A GENERALIZED MATERIAL HANDLING
SIMULATION SYSTEM

by

Charles Edmond Donaghey, Jr.

B.S. in I.E., Pennsylvania State University, 1952

M.S. in I.E., University of Pittsburgh, 1959

Submitted to the Graduate Faculty

of the School of Engineering

in partial fulfillment of

the requirements for the degree of

Doctor

of

Philosophy

University of Pittsburgh
1967

TABLE OF CONTENTS

Page

FOREWORD. i

I. INTRODUCTION. 1

II. DESCRIPTION OF THE MODEL 9

III. MHSS COMPUTER PROGRAM. 28

IV. TESTING THE MODEL. 74

V. CONCLUSION 121

APPENDIX A 125

BIBLIOGRAPHY .130

FOREWORD

Acknowledgment is made to the Wunsch Material Handling Foundation who furnished interest and financial support for this dissertation.

Computation time for this dissertation was obtained at the University of Pittsburgh Computing Center, which is partially supported by the National Science Foundation Grant Number G-11309.

I. INTRODUCTION

The use of computer simulation has become recognized as a valuable tool to the operations researcher and management scientist. Problems have been solved using simulation in a fraction of the cost and time that exact methods would take, if indeed an exact method were feasible. However, the use of computer simulation requires sophisticated computer programming skills. Simulation languages such as SIMSCRIPT(1)* and GASP(2) have reduced the programming skill required, but not to a level where they can be used by a busy engineer or manager, unless he has extensive programming experience. The engineer or manager, therefore, must communicate his problem to a programmer, which at times can prove to be a frustrating experience, especially if the programmer has no previous knowledge of the system he is to simulate.

Once the communications problem has been overcome, the engineer or manager must wait until the programmer develops the computer model. If the decisions to be made as a result of the simulation are critical with respect to time, the entire value of the simulator is lost if a great deal of time is involved in its development. As a result, simulation

---

*Parenthetical references placed superior to the line of text refer to the bibliography.

models are not very often developed, unless it is a model that will be used repeatedly, and the decisions resulting from the model are such that they warrant the great deal of time and cost required in the development of the model.

The engineer or manager with a deadline of two weeks for a decision feels, and correctly so in most cases, that simulation is not a readily available tool he can use to help him make this decision. This dissertation will attempt to make simulation a desirable tool to use in many of these situations. A new simulation language will not be presented. With even the simplest of simulation languages, the construction of a computer model is still time consuming. Instead, a completed computer model of a very common real life situation has been structured, and the user simply furnishes data parameters to this model for his own problem.

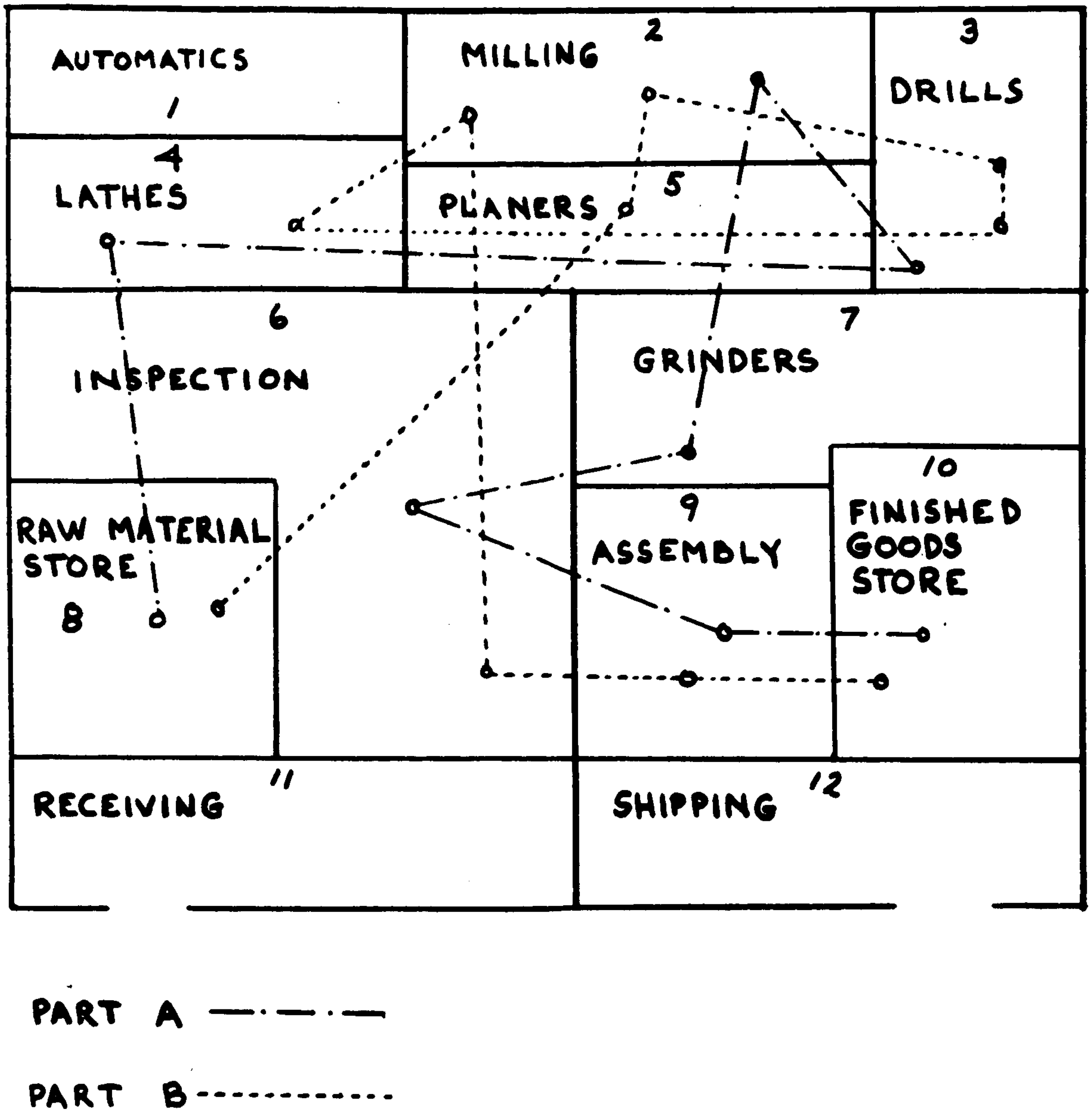
The field of material handling was selected as the area where this model will apply. The material handling area was selected for several reasons. First, there appears to be a demand for simulators in this field; second, material handling systems seem to follow a general model and, last, the Wunsch Material Handling Foundation was interested in sponsoring research in this area.

Perhaps the main contribution of this dissertation will be the generalized material handling model that will be presented. In all the cases where simulation was previously used in the material handling area, the developers assumed their problems and situations unique. The simulation models, therefore, had little universal application. However, material handling systems do follow a general model and this model will be discussed in this dissertation.

As stated previously, a great deal of work has been done in material handling simulation. It might be well to review some of this work. Perhaps the most well known computer program in this area is the CRAFT program (Computerized Relative Allocation of Facilities Technique) developed by Buffa, Armour, and Vollman[3]. While this program is intended as a tool for determining the evaluations of plant layouts, the areas of plant layout and material handling are so close, that a discussion of CRAFT would not be out of order. Assume a block diagram of a machine shop layout is as shown in Figure 1.

The flow paths for the two parts in Figure 1 are almost entirely different. In a really complex jobbing machine shop, there may be hundreds, or even thousands of products being processed, and it is conceivable that they may all be different, each requiring a different sequence of processes. The problem, therefore, is to conceive a plant layout that

1. Takes account of the wide variations of flow paths
2. Allows for different material handling systems for different materials or parts



BLOCK DIAGRAM OF MACHINE SHOP

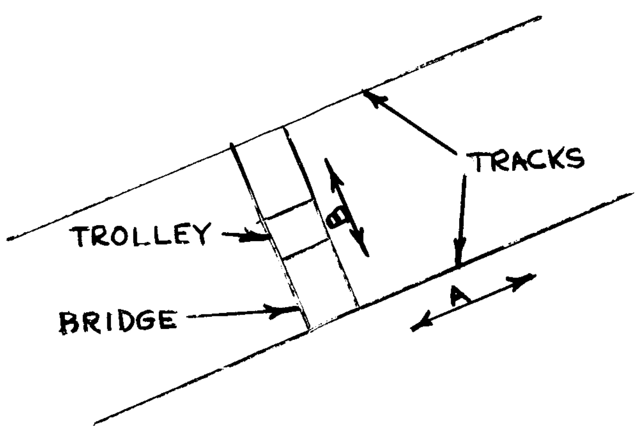
Figure 1

3. Takes account of the differing floor-area requirements of departments
4. Meets requirements of certain departments for certain locations
5. Minimizes material handling costs

As inputs, the CRAFT program takes data on interdepartmental flow and material handling costs, together with a representation of a block layout which is basically similar to Figure 1. The block layout may be the actual existing layout, or if a new facility is being developed, any arbitrary starting solution. Within the computer, the locations of two arbitrary departments are exchanged and the material handling costs after this exchange are computed. The first pair of departments is put back in their original locations and a second pair selected, and the cycle is repeated. This is done until all possible exchanges are examined. The program then selects the exchange which resulted in the greatest cost reduction and fits this exchange on the block layout. The new material handling costs, and the revised block layout are then printed out. In the block layout shown in Figure 1, there are 12 departments. The program, therefore, would examine 66 exchanges if presented with this layout ($C_2^{12} = \frac{12!}{2!\ 10!} = 66$). The basic procedure is again repeated with the revised layout until the program determines that no exchange in locations can be made which reduce material handling costs. CRAFT examines only a very small percentage of the possible layouts.

With only 12 departments, there are still over one billion possible layouts (12!). For this reason, CRAFT has been discounted by some writers in the material handling field. However, its developers can point to a number of successful applications of CRAFT.(3)

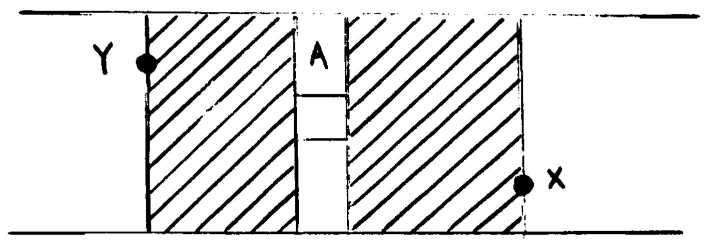
Another use of simulation in the material handling area was reported by Lave and Taha.(4) The program was used to investigate interference between cranes used for material handling purposes.



CRANE SYSTEM

Figure 2

As shown in Figure 2, the basic members of the crane system in the program are the tracks, the bridge, and the trolley. The bridge moves along the tracks in direction A, and the trolley moves along the bridge in direction B, making lifts and moves with a hoisting device attached to it. A crane in the program is defined as one bridge and one trolley. Several cranes can operate on the same set of tracks, and thus while one crane is performing a move in an area, this area will be unable to get additional crane service until this move is completed. Figure 3 shows crane A executing a move from X to Y.



CRANE MOVE

Figure 3

In the Lave-Taha program, the shaded area can get no additional crane service until this move is completed. Any demand for crane service to the left of the shaded area can only be filled if there is an idle crane to the left of crane A. Likewise, any demands to the right can only be filled if there is an idle crane to the right of crane A.

The main purpose of this simulation was to determine the effect of interference between cranes in a typical industrial situation. It was found that the effect of crane interference can be a major cause of idle time for the machines they are serving.

Mr. O. R. Hunley[5] of General Electric published the results of a material handling simulation program he developed.

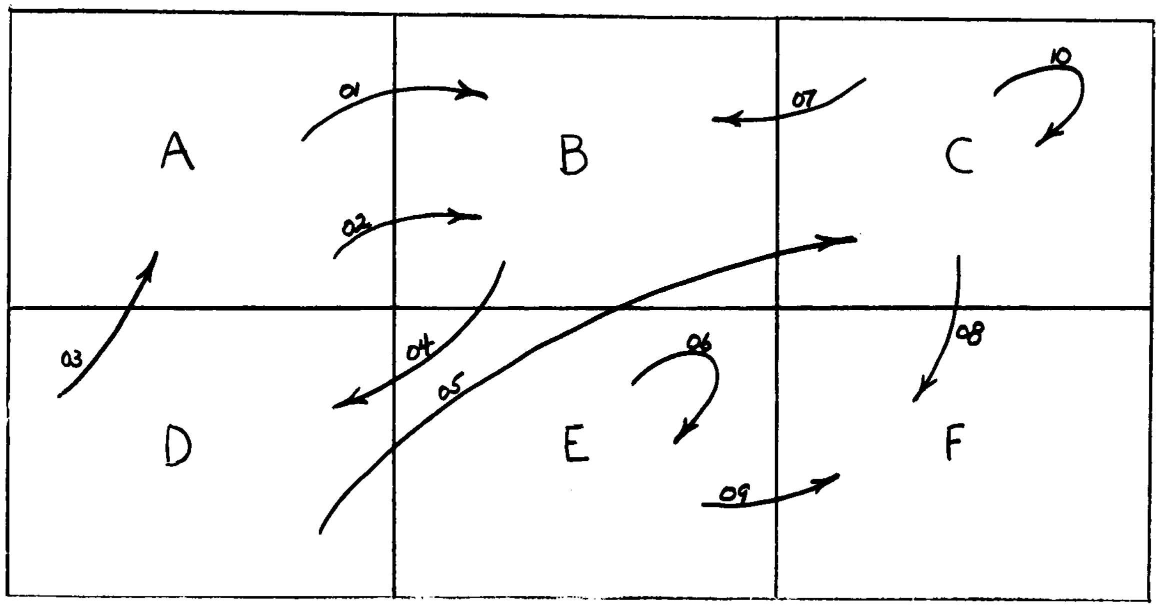
In this program, he simulated various conveyor systems for one of their plants, and determined which layout would best fit their needs. A number of other simulations of this type have been developed. Their object is to solve one specific problem. Typical questions answered by simulation are--how many fork lift trucks should be purchased; how many cranes installed; when should extra handlers be used in the department; what is the best routing for delivery trucks. All the simulators prepared for these problems, however, are designed specifically for one situation, and would be of little use unless one happened to have the same real life situation.

The bibliography shows some of the other work investigated. In every case where simulation was used in the area of material handling, it was used to either solve a specific problem or to gather analytical data to support theory. The leading educators in the material handling field were contacted in order to determine if someone else has done work in developing a general material handling simulation model. Professor Elwood Buffa of U.C.L.A., Professor James Moore of Northwestern, Professor Richard Wilson of Michigan, Professor Hew H. Young of Purdue, and Professor James Apple of Georgia Tech all stated that they know of no similar work.

In the following pages, first will be presented a description of the generalized material handling model. Next, a computer program of this model will be discussed, and then the results of actual application of this program will be reported.

II. DESCRIPTION OF THE MODEL

In referring to the model to be described, the abbreviation MHSS will be used for Material Handling Simulation System. In Figure 4 the block layout of a typical system to be simulated is shown.



BLOCK LAYOUT OF A MATERIAL HANDLING SYSTEM

Figure 4

The rectangles A, B, C, D, E, F could represent machines in a machine shop, departments in a hospital, areas of a city, or any other breakdown of the system to be simulated. The breakdown may be by area, by component, or by function. MHSS is not intended to be just an industrial simulator. It has application whenever material handling is a problem. The arrows in Figure 4 could be the various material handling moves required to service this system. In order to utilize MHSS, the user must first answer questions concerning the moves and the equipment that is to execute the moves. The move questions are as follows:

1. During what period of time is it possible for the move to occur?
2. What is the time interval between demands for the move?
3. How long does the move take?
4. What equipment and/or personnel are required for the move?
5. While the move is being executed, does it interfere with the execution of other moves?
6. Are there alternate ways of executing the move?
7. Does the move generate following moves?

Each one of these move questions will now be examined in more detail.

1. <u>During what period of time is it possible for the move to occur?</u>

In using MHSS, it must be decided what is the length of time that constitutes a cycle. This can be an eight-hour shift, a twenty-four hour day, a thirty-day month, or any other desirable cycle length. Once this has been decided, it must be determined for each move, when in this cycle length the move can occur. For example, assume the rectangles in Figure 4 represent areas in a machine shop, and the cycle length is an eight-hour shift. Move 01 is a move from area A to area B and can occur anytime within the shift. Therefore, the period during which it is possible for the Move 01 to occur is from t = 0 to t = 8. Perhaps, Move 09 is the move of scrap from E to F and only occurs at the end of the shift. Therefore, Move 09 can only take place from t = 7.75 to t = 8.

2. <u>What is the time interval between demands for the move?</u>

For moves that reoccur during a cycle, the time interval between demands for the move must be specified. Few demands for moves occur with exact regularity. For this reason, MHSS provides a number of statistical distributions for the user. When using these distributions, the user supplies the parameters, and MHSS will then sample from the desired distributions during execution.

3. <u>How long does the move take?</u>

The length of time a move takes is from the time the equipment and/or personnel that are to execute the move first become occupied with the move, until the time they are free to execute another move. The length of time for the move can either be a constant or again the statistical distributions can be utilized.

4. <u>What equipment and/or personnel are required for the move?</u>

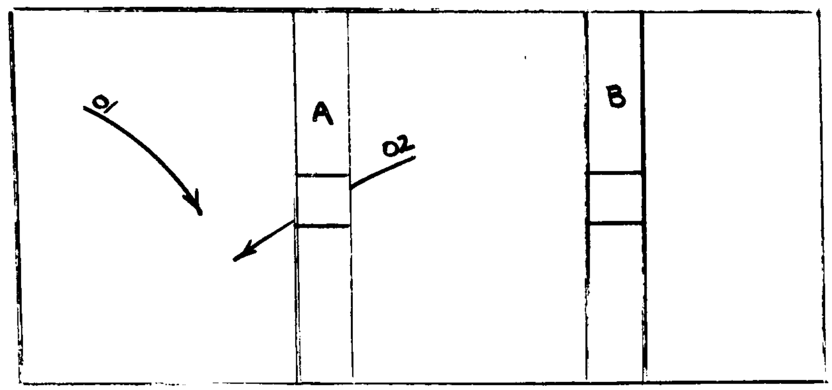
By components, are meant the material handling equipment and personnel that a move must have before the move can take place. For example, consider the movement of cores by crane from one area to another in a foundry. The components for the move would be the crane and the hook-up man. The move cannot be executed until both components are free, and execution of the move is completed when both components are again free.

The basic MHSS model allows up to three components to execute a move. A maximum of three components appears to be adequate for most problems; however, the model can easily be changed to handle more components if this proves necessary.

5. <u>While the move is being executed, does it interfere with the execution of other moves?</u>

MHSS will automatically check if the required equipment and/or personnel are available before executing the move. However, there are some moves that cannot be executed while other moves are taking place, even if the components necessary to execute the move are available. The crane interference discussed in the introduction would be a good example of this situation. A diagram of this occurrence is shown in Figure 5.

Move 01 requires crane B to execute the move. Crane B is idle and available for the move. However, Move 02 utilizes crane A and is now in progress. Crane B cannot get to the required location for Move 01, and therefore, Move 01 is blocked. Move 02 would be referred to as a blocking move, and the moves it blocks would be listed.



CRANE BLOCKING

Figure 5

6. Are there alternate ways of executing the move?

If the demand for a move occurs, and the execution components are not available, or the move is blocked, there may be alternate ways of performing the move. Use of a fork lift truck instead of the overhead crane, use of an automobile instead of a delivery truck, would be examples of alternate ways of executing a move.

7. Does the move generate following moves?

Some moves trigger moves which follow them. The following move may occur immediately upon completion of the move that triggers it, or may occur sometime later. For example, consider the move of a part to a heat treating furnace. The completion of this move will schedule the move where the part is taken from the furnace after treatment. The length of time preceding the following move is specified by the user. It can be a constant time, or a time drawn from the available statistical distributions. One move can trigger any number of following moves.

After the move questions have been answered, the user must now deal with the equipment and/or personnel that will execute the moves. In the remainder of the dissertation, equipment and/or personnel will be referred to just as equipment; however, it is to be understood that a piece of equipment may actually be a human material handler. The equipment questions to be answered are:

1. During what period of time is the equipment available?
2. What proportion of the availability period is the equipment able to execute moves for the system being simulated?
3. When the equipment is not available to the system being simulated, how long is it not available?

1. <u>During what period of time is the equipment available</u>?

Some equipment may not be available for the entire cycle length. A fork lift truck, for example, may only be available to the department whose material handling system is being simulated for the last four hours of the eight-hour shift. If the cycle length is assumed to be eight hours, then the time the truck is available would be from $t = 4$ to $t = 8$.

Equipment that is available for the entire shift would have as its period of availability from t = 0 to t = 8. This does not mean that the equipment will always be available during this specified interval, but it does mean that it is possible for the equipment to be available during this period. For the fork lift truck that had an availability period from t = 4 to t = 8, it will never be available from t = 0 to t = 4. However, it may need repair or be required someplace else during the period t = 4 to t = 8.

2. What proportion of the availability period is the equipment able to execute moves for the system being simulated?

The MHSS user must determine what proportion of the available time the equipment is actually available to perform the material handling function in the system being simulated. The availability period for a piece of equipment could be from t = 0 to t = 8, but during this period it may only be actually able to execute moves, on the average, 90 per cent of the time. The other 10 per cent of the time the equipment may be receiving repairs, or servicing another department or areas not included in the simulation. The proportion of time available then would be .90. MHSS assumes that time periods when the equipment is not actually able to execute moves during the availability period to occur in a random manner.

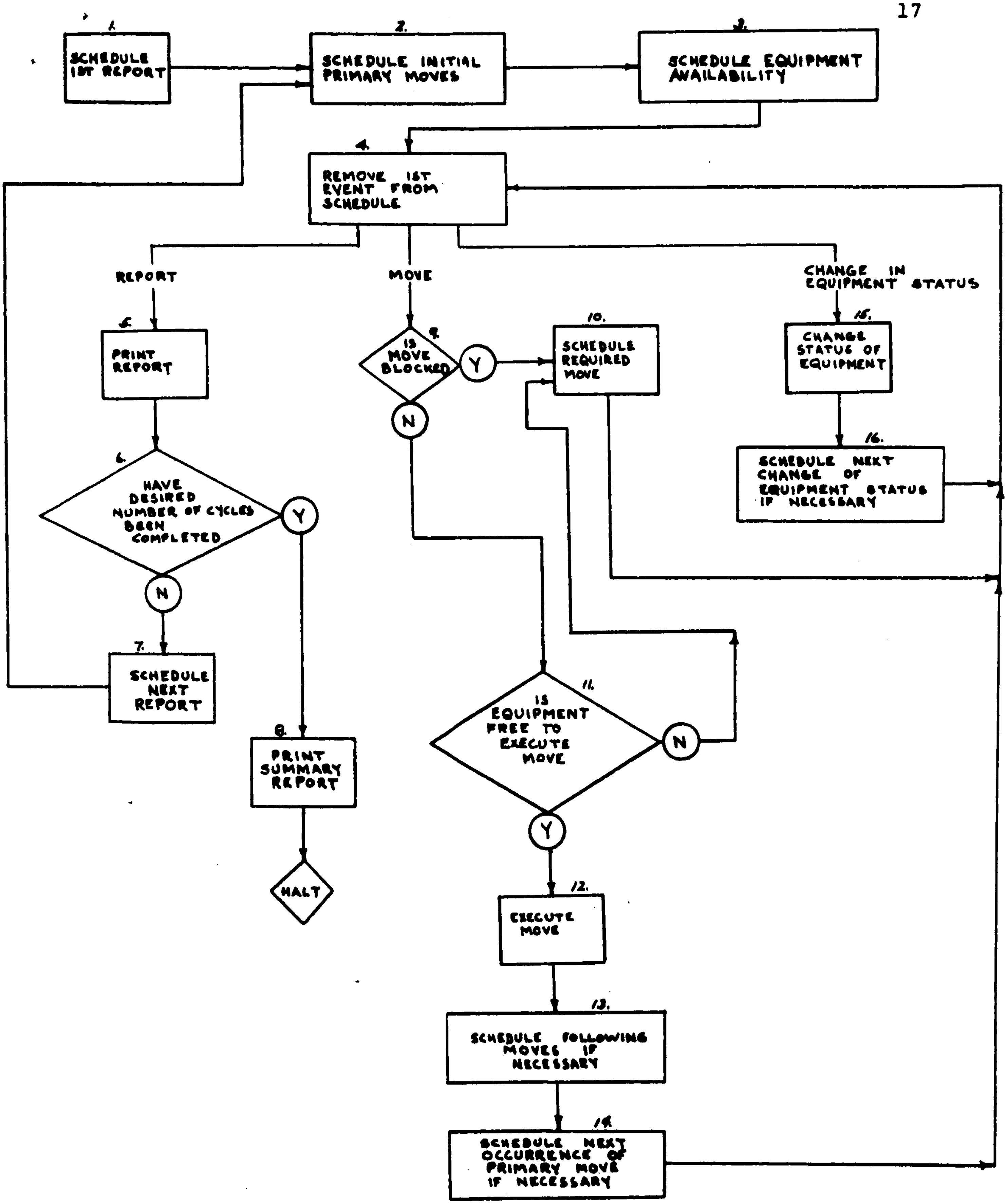
3. <u>When the equipment is not able to execute moves for the system being simulated, how long does this period last?</u>

MHSS also requires information on the length of time a piece of equipment is not able to execute moves during the availability period. Consider the example presented in the discussion of the previous question, where a piece of equipment is actually available 90 per cent of the time during a cycle of eight hours. This 90 per cent average could have been determined from a situation where the equipment is actually available 100 per cent of the time for nine days and then was down completely for the tenth. Or it could have been determined from a situation where the average length of unavailability was two minutes, and the average number of these unavailable periods was 24 during an eight-hour day. In either case, the proportion of time available would be .90. Therefore, the user must furnish MHSS with information on the length of time the equipment is not able to execute moves during the availability period.

The data obtained from the answers to the move and equipment questions are the parameters to the MHSS model. The model in flow chart form is shown in Figure 6. Each block of the flow chart will now be examined.

1. <u>Schedule First Report</u>

MHSS provides a report at the end of each cycle. This report will give the total amount of handling time for each



BASIC MHSS FLOW DIAGRAM

Figure 6

move, the number of times each move occurred, and the total amount of time each move had to wait for service. The time each piece of equipment is busy, idle, and the time it was unavailable to the system being simulated is also reported. MHSS keeps a schedule of all events that occur during the simulation. There are three types of events that can occur during a cycle: reports, moves, and changes in equipment status. The first type is a report and in Block 1, the first report is initially scheduled to occur.

2. Schedule Initial Primary Moves

MHSS uses three main categories of moves. They are primary moves, optional moves, and following moves. A primary move is a move that occurs entirely on its own during the cycle. A following move is a move that is triggered by the completion of some other move, and an optional move is a move that only occurs when a primary or a following move cannot take place. Primary moves occur at random during the cycle, or the time between demands for these moves may be rigidly specified. In Block 2, the initial occurrences of all the primary moves are scheduled.

3. Schedule Equipment Availability

In the simulation, each piece of equipment has a tag that keeps track of when the equipment will be free to execute moves. For example, if a piece of equipment is in the process of executing a move that will be completed at t = 10.15, then the tag for this equipment would be 10.15. Initially, the tag for each piece of equipment will be set to the time of the start of the availability period for each piece of equipment.

4. <u>Remove First Event From Schedule</u>

MHSS will take the event with the earliest chronological time from the schedule. It will examine this event to determine if it is a report, a move, or a change in equipment status. For events that are scheduled to occur at the same time, changes in equipment status will be executed first, moves second, and reports third. Changes in equipment status will be executed first, since many times these changes in status represent equipment breakdown. For simplicity, MHSS does not allow equipment to break down while executing a move. For example, consider the case where a piece of equipment coded EX is in the process of executing a move that is to be completed at $t = 10.23$. If at time $t = 10.20$, a change in equipment status for EX occurs, and this change in status represents a breakdown, the breakdown will be delayed until $t = 10.23$. If another move is waiting for EX, and moves had precedence over changes in equipment status, the breakdown would again be delayed. Therefore, changes in equipment status are given highest priority.

Not allowing changes in equipment status while the equipment is executing a move did not appear to affect the realism of the model in the situations where it was tested. However, if it is desired to simulate a move that will occupy equipment for a large percentage of the simulation cycle, it would be desirable to break the move down into smaller segments so the equipment would have a chance to break down.

For example, consider move MA that requires equipment EX. MA requires three hours for execution and the cycle length is eight hours. It would be better to break this move down into, say, one-half hour segments where MA_1 would be a primary move requiring one-half hour, MA_2 a following move that is triggered by the completion of MA_1 and also requires one-half hour, MA_3 a half hour following move that is scheduled immediately upon the completion of MA_2 and so on, until the entire three hour move is accounted for by the single one-half hour primary move and five following moves each of one-half hour duration. In this way, any breakdown of EX would not be excessively delayed, since MHSS would determine each half hour during the execution of the move if any equipment breakdown took place.

Reports are give lowest precedence for events that are to occur at the same time, since they only occur at the end of simulation cycles, and all other activities that are to occur at that time should be attended to before the cycle is ended. MHSS will also recognize priorities for moves. If a user has assigned priorities to moves, and two or more become scheduled to occur at the same time, MHSS will then select the move with the highest priority, and execute this move first. If priorities are not used, and two or more are to occur at the same time, then the move that was assigned to the schedule first will be executed first.

5. Print Report

Figure 7 shows a typical end of cycle report from MHSS. The time at the end of the cycle is shown along with the cycle number on the first line of the report. Following this, for each move, there is the code assigned to the move, the total waiting time for the move during the cycle, the number of times the move occurred, and the total material handling time required for the move. Next, for each piece of equipment, the total time the equipment was working, the total time it was idle, and the total time it was not available to execute moves during the simulation cycle. Averages to date are also printed.

6. Have Desired Number of Cycles Been Simulated

The user will specify to MHSS how many simulation cycles he desires to be executed. After each cycle, MHSS will determine if this desired number has been satisfied.

7. Schedule Next Report

If the desired number of cycles has not been executed, MHSS will set the clock to 0, schedule the report at the end of the next cycle and go back to Step 2.

8. Print Summary Report

If the desired number of cycles has been executed, a summary report will be given. This report gives the average

REPORT AT 8.00 CYCLE NUMBER 2

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.00	2	.09	.01	2.00	.17
402	.00	0	.00	.04	2.00	.22
401	.00	0	.00	.00	.00	.00
403	.00	3	.41	.49	3.50	.36
404	.00	0	.00	.00	.00	.00
405	.00	3	.35	.00	2.50	.31
406	.11	1	.07	.07	1.00	.07
407	.00	3	.34	.52	2.50	.28
409	.15	1	.09	.08	1.00	.07
410	.08	1	.13	.79	1.00	.09
414	.00	1	.12	.04	1.00	.09
471	.00	1	.09	.00	.50	.04
472	.00	1	.13	.00	.50	.06
XRY	.00	0	.00	.00	.00	.00
SHP	.32	6	.73	.22	5.50	.59
OUT	.00	2	.31	.03	1.50	.19
800	.00	2	.18	.01	2.50	.25
700	.00	0	.00	.00	.50	.02
NTK	.78	34	4.35	.45	32.00	3.85

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	2.99	5.01	.00	2.32	4.10	1.58
FT	.04	1.90	6.06	.51	3.18	4.31
OP	4.07	3.93	.00	4.09	3.91	.00
OP	3.31	4.69	.00	2.59	5.41	.00

TYPICAL END OF CYCLE REPORT

Figure 7

values of the variables reported in the end of cycle reports, over the number of cycles executed. Upon completion of this report, the simulation is finished.

9. Is Move Blocked

Once MHSS has determined a move is to occur, it first investigates to see if any other move is in progress that blocks the move.

10. Schedule Required Move

If the move that is to occur is blocked by a blocking move already in progress, MHSS will look ahead to see when the blocking move will be completed. If the move that is to occur has no optional move, the move will be put back in the schedule to occur at the time the blocking move is completed. If the move does have an option, however, MHSS must determine if an attempt should be made to execute the option. In preparing data for MHSS, the user must specify how long he is willing to have a move wait, rather than have an optional move executed. For example, a primary move might require an overhead crane as its material handling equipment. An optional move for this primary move might require a fork lift truck. When a demand for the primary move occurs, and the move cannot immediately be executed, perhaps because of blocking, MHSS will not always immediately attempt the optional move with the fork lift truck. It would not be too realistic to assume that a machine operator will begin to unload his machine with a fork lift truck, when the overhead crane which can much more easily execute the move will be available in three minutes. It would be a different situation if the crane was going to be blocked or otherwise unavailable for an hour. In that case, he would probably use the truck to unload his machine, rather than wait an hour for the crane.

The MHSS user must specify to the model how long a move should be allowed to wait rather than use an optional move. During execution, MHSS assumes that the time a blocking move will be completed or equipment will become available is known. In the above example, assume the user had specified the primary move could wait as much as five minutes rather than immediately execute the fork lift truck move. Assume a demand for the primary move occurred at 10:00, and it was found the move was blocked. The blocking will last until 10:20. In this situation, MHSS would initiate the optional move at 10:00. If the blocking move was due for completion at or any earlier than 10:05, then the primary move would be delayed until then, since the option is only used if it is determined the primary move must wait more than five minutes.

11. Is Equipment Free to Execute Move

If no blocking was found for a move, MHSS then checks for equipment availability. Each piece of equipment required for the move must be free. If it is not free, and the move has no option, the move will immediately be rescheduled to occur when the equipment will be free. If the move has an option and the time until the equipment will be free is longer than the time the user specified the move should wait, the option is scheduled to occur immediately.

12. Execute Move

When it has been found that the move is not blocked, and the equipment required to execute the move is free, the move is started. The length of time the move is to take will be determined from the specifications furnished by the user. The tags on the required equipment will be changed to show when the move will be completed, and the equipment is again available to execute other moves. Tags and tallies connected with the move will be changed and up dated to keep track of the number of times the move occurred, the length of time the move was delayed, the length of handling time, and other data needed for reporting and operation of the model.

13. Schedule Following Moves

If the move has any following moves that are to occur immediately upon its completion or some time after its completion, they are then added to the schedule along with the time they are to occur. Primary, optional, and following moves themselves can all have following moves.

14. Schedule Next Occurrence of Primary Move if Necessary

If the move that has just been started is a primary move, the next occurrence of the move will be added to the schedule. The parameters which the user furnished MHSS concerning the time between demands for each of the primary moves are used in determining when the next occurrence of a given primary move will take place.

15. <u>Change Status of Equipment</u>

The third type of event MHSS can find in the schedule is a change of equipment status. There are two ways that equipment can change its status. It can become available to the system being simulated or, the second way, it can become unavailable to the system. Equipment in the process of executing a move for the system being simulated does not have its status changed when it completes the move. While in the process of executing a move for the system, it is still considered by MHSS to be available to the system. A change in equipment status would be events such as equipment breaking down, equipment returning from a breakdown, equipment going to another department not included in the simulation, and equipment returning from another department. If the event is a piece of equipment becoming available to the system, the tag for the equipment which records when the equipment will be available is changed to contain the current time. If the event is a piece of equipment becoming unavailable to the system, MHSS must determine when it will next become available, and record this value in the availability tag for the equipment.

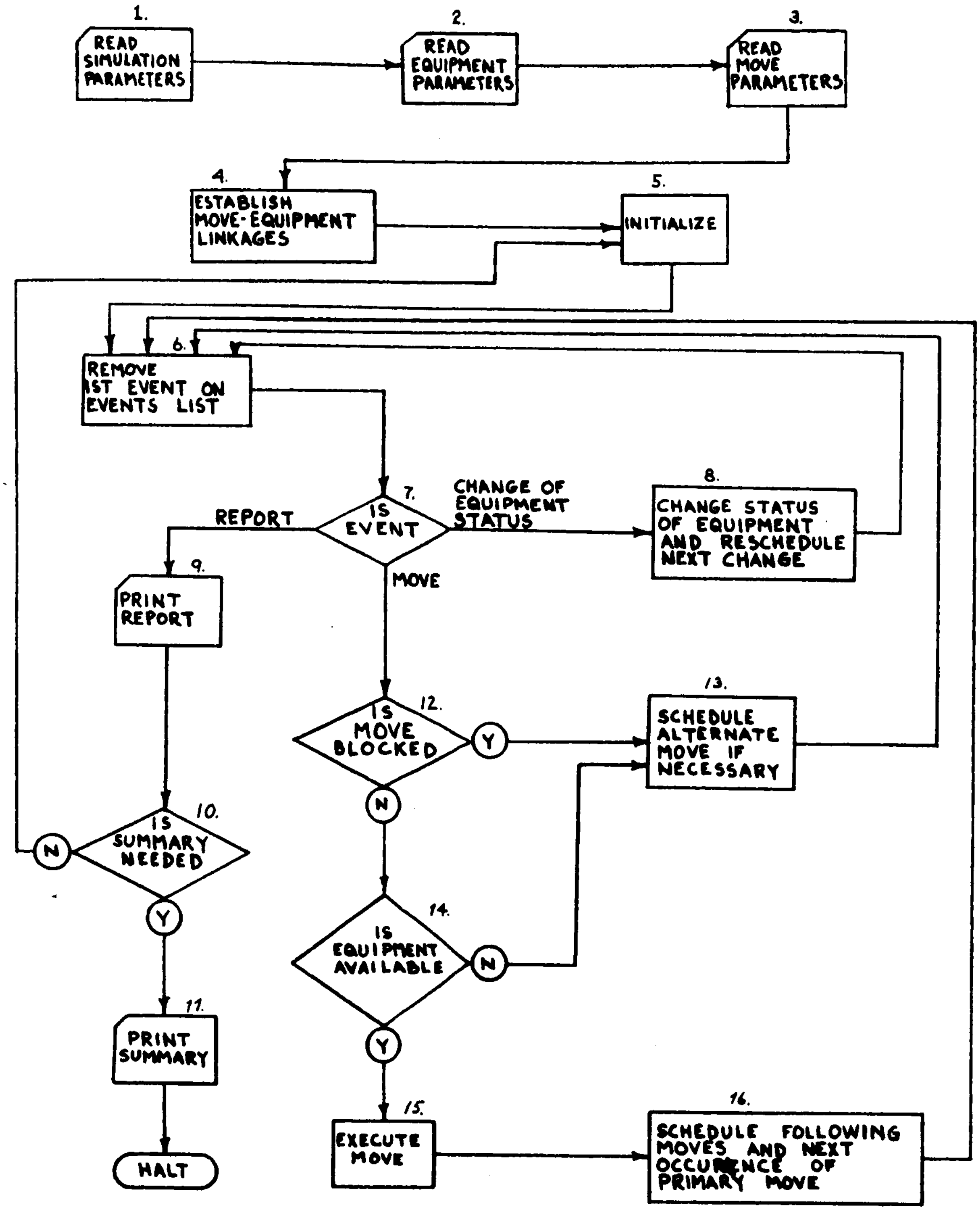
16. Schedule Next Change of Equipment Status if Necessary

Each time a piece of equipment changes its status, the time for the next change is determined and this event added to the schedule. For equipment that is becoming unavailable to the system for the remainder of the cycle, no new change of equipment status event need be added to the schedule. For example, consider a piece of equipment that is available 100 per cent of the time from $t = 0$ to $t = 4$ during an eight hour cycle. When time reaches $t = 4$ and the event occurs when the equipment becomes unavailable, no new event concerning this equipment need be added to the schedule. However, if the user said the piece of equipment was only available 50 per cent of the time during this period, at some time during the availability period, $t = 2.49$ for example, it would be possible that the piece of equipment might become unavailable to the system for .25 hours. In this case, the return of the equipment to the system must be added to the schedule to occur at $t = 2.74$. If the proportion of time the equipment is not actually available to the system during its availability period is less than 1.0, MHSS will assume the times the equipment leaves the system to occur in a random manner.

III. MHSS COMPUTER PROGRAM

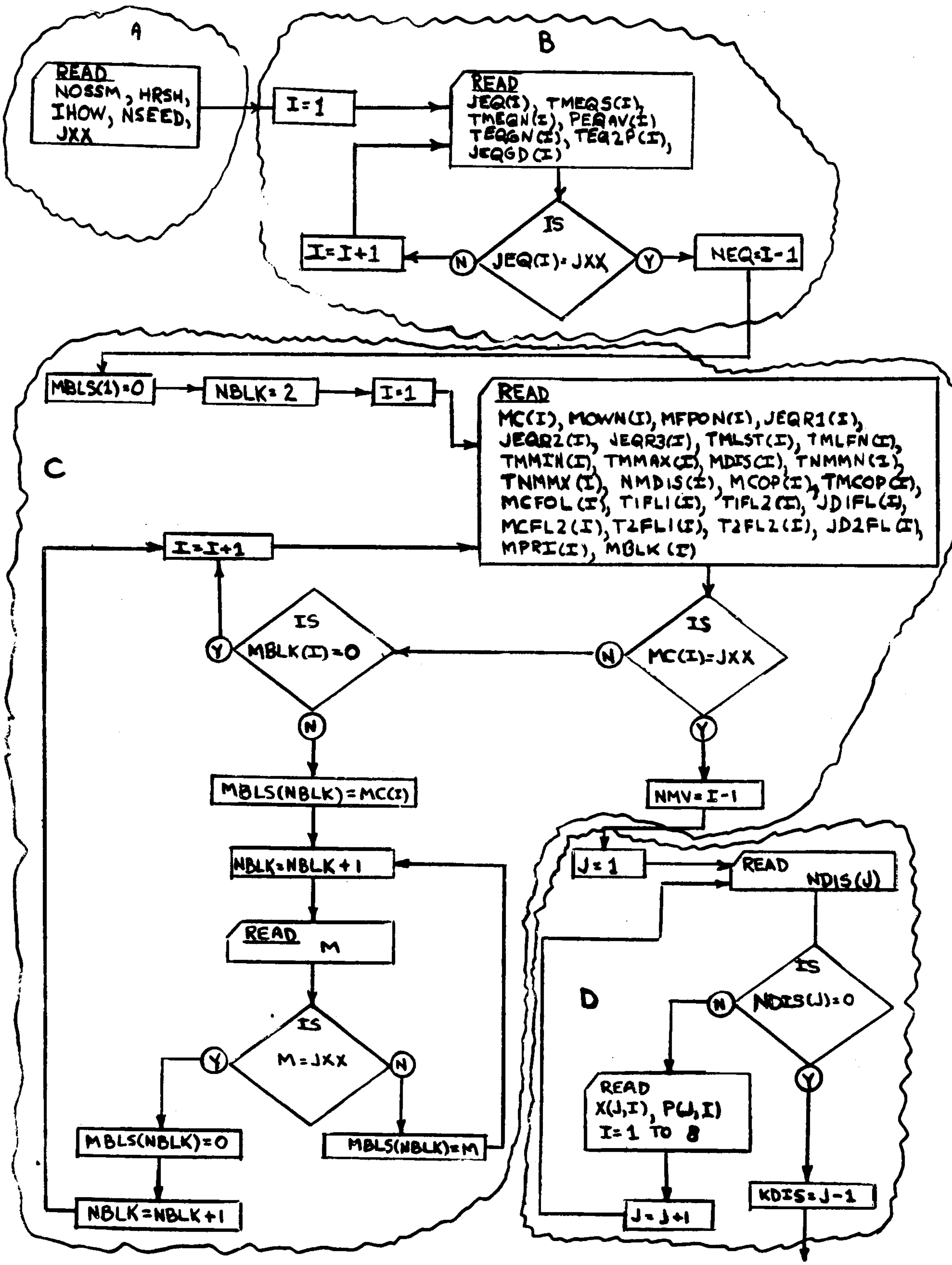
Fortran II was selected as the computer language for programming MHSS. Fortran II was selected over simulation languages SIMSCRIPT, GASP, and GPSS which were available and would have made the programming easier, for several reasons. First, it was desired to make MHSS as universal as possible, and the number of computer installations which have Fortran readily available far outnumber those that have the simulation languages mentioned. Second, none of the three simulation languages mentioned are in the operating system at the University of Pittsburgh Computing Center where this work was done. Therefore, it was impossible to run programs written in these languages under the regular batch processing system. Turn-around time thus would have been much greater had any of these languages been used. Fortran II was chosen over MAD, a more powerful compiler language available in the operating system at Pitt, again to make MHSS more universally capable of being utilized.

Figure 8 is a flow chart of the program. As expected, the program flow chart is very similar to the model flow chart in Figure 6. Blocks 1, 2, and 3 of the flow chart represent the operations to get the simulation parameters into the computer. Figure 9 shows these input operations in more detail. This input flow chart has been divided into four segments A, B, C, and D for ease of explanation. In segment



MHSS PROGRAM FLOW CHART

Figure 8



MHSS INPUT FLOW CHART

Figure 9

A, a single card is read that contains information as to the length of the simulation cycle, and the number of cycles that are to be simulated. These two variables are called:

NOSSM - The number of cycles to be simulated

HRSH - The length of a simulation cycle

In addition, three other variables are read from this first card.

IHOW - A single digit number that when set to zero will cause a report to be printed at the end of each simulation cycle. When set to any non-zero value, only the summary report at the end of all the cycles to be simulated will be printed.

NSEED - MHSS utilizes a uniformly distributed random number generator of numbers between 0 and 1. NSEED is a five digit number used as a seed for this random number generator.

JXX - A three column blank field read under an alpha format to be used for comparison purposes.

There are only two system functions assumed by MHSS. These are the random number generator called by RANDOM, and $\log_e$ called by ELOG.

In Segment B, the equipment parameters are read. An initial index I is set to 1, and then the equipment variables for the first piece of equipment are read.

JEQ - A three character code assigned by the user for a piece of equipment.

TMEQS - The start of the availability period for the equipment.

TMEQN - The end of the availability period for the equipment.

PEQAV - The proportion of time the equipment is actually available to the system during the availability period.

TEQGN - First parameter for the length of time the equipment is gone during the availability period.

TEQ2P - Second parameter for the length of time the equipment is gone during the availability period.

JEQGD - The statistical distribution to be utilized when determining the length of time the equipment is gone. For example, if JEQGD is 3, the distribution is normal and MHSS would use TEQGN as the mean and TEQ2P as the standard deviation.

The equipment parameter cards will continue to be read, one card for each piece of equipment. Each time a card is read, JEQ(I) is compared with JXX, the blank alpha variable. If the two variables do not compare, I is incremented and another card read. If the two variables do compare, MHSS assumes the end of the equipment list and sets NEQ equal to I-1. NEQ is the number of pieces of equipment in the simulation. It may not be the same as the actual number of pieces in the system being simulated. Consider, for example, the situation where a piece of equipment is available to a system for the first two hours of an eight-hour shift, and then again for the last two hours of the shift. There would be one data card showing a piece of equipment with an availability period from t = 0 to t = 2, and a second card showing a piece of equipment with an availability period from t = 6 to t = 8. MHSS would thus treat the single piece of equipment as two separate pieces.

After the equipment list has been read, MHSS is now ready to bring in the move parameters. These operations are shown in Segment 2 of Figure 8. The first step is to initialize the blocking list. The blocking list contains all the blocking moves and all the moves they block. Each blocking move and all the moves it blocks form sub-lists in the blocking list. The sub-lists are separated by zeros in the blocking list. For example, suppose M1 is a blocking move and the moves it blocks are M3, M8, and M9. Suppose M5 is another blocking move and the moves it blocks are M3, M6, M7, and M12. The blocking list then would appear in Figure 10.

Cell No.	Blocking List
1	0
2	M1
3	M3
4	M8
5	M9
6	0
7	M5
8	M3
9	M6
10	M7
11	M12
12	0

BLOCKING LIST

Figure 10

The blocking move is the first move after the zero, and the moves it blocks continue until another zero is encountered. Each element of the blocking list is called MBLS(I), and the next cell to be utilized on the blocking list is called NBLK. In the example shown in Figure 10, NBLK would be 13. Therefore, in initializing the blocking list, MBLS(1) is set to zero, and NBLK set to 2. The move parameters are then brought into the computer, one move per card. The variables are as follows:

MC - A three character code assigned to each move by the user.

MOWN - If the move is an optional move, the name of the move which owns it.

MFPON - If the move is a following move, this variable is set to one, otherwise set to zero.

JEQR1 - The first piece of equipment required for the move.

JEQR2 - The second piece of equipment required for the move.

JEQR3 - The third piece of equipment required for the move.

TMLST - The start time for the period when the move can occur.

TMLFN - The finish time for the period when the move can occur.

TMMIN - The first parameter for the time the move requires. For example, for a normal distribution this would be the mean.

TMMAX - The second parameter for the time the move requires. For a normal distribution this would be the standard deviation.

MDIS - The statistical distribution for the move time. The normal distribution is code 3.

TNMMN - The first parameter for the time between moves.

TNMMX - The second parameter for the time between moves.

NMDIS - The statistical distribution for the time between moves.

MCOP - The move code of the optional move, if it exists.

TMCOP - The time the move can wait, rather than execute the option.

MCFOL - The move code of the first following move.

T1FL1 - The first parameter of the time until the first following move is executed.

T1FL2 - The second parameter of the time until the first following move is executed.

JD1FL - The statistical distribution of the time until the first following move.

MCFL2 - The move code of the second following move.

T2FL1 - The first parameter of the time until the second following move is executed.

T2FL2 - The second parameter of the time until the second following move is executed.

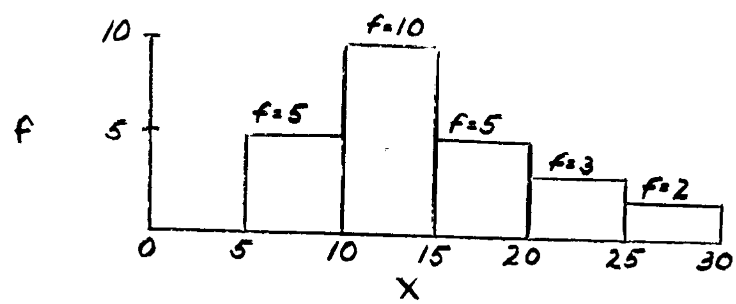
JD2FL - The statistical distribution of the time until the second following move.

MPRI - The priority of the move. Lowest priority zero.

MBLK - If the move is a blocking move this variable is set to one, otherwise it is zero.

MHSS will continue to read move cards until a blank card is encountered. When the blank is encountered, MC(I) will be the same as JXX, and the number of moves in the simulation, called NMV, will be set to I-1. Anytime the variable MBLK(I), is found to be non-zero, the I'th move is considered to be a blocking move. MC(I) is then put in the next available position on the blocking list, and the cards which follow will have the move codes of the moves it blocks. These cards will continue to be read, until again a blank is encountered. This is the indication that the end of the list of moves which are blocked has been found. MHSS then goes back to bring in the next move and its associated parameters.

In Segment D, MHSS brings in the statistical distributions the user wishes to furnish. MHSS has a number of built in distributions. For examples, statistical distribution 3 is a normal distribution, 2 is an exponential distribution. Distributions 12 through 20 are Erlang distributions, with 12 a class 2 Erlang, 13 a class 3, etc. Any distribution numbered over 20 must be furnished by the user. To do this, he furnishes points from the cumulative distribution of his function. For example, assume a histogram of some data appears as in Figure 11.



HISTOGRAM

Figure 11

The cumulative relative frequencies are determined in Figure 12.

X	Cumulative Frequency	Cumulative Relative Frequency
5	0	0
10	5	.20
15	15	.60
20	20	.80
25	23	.92
30	25	1.00

CUMULATIVE RELATIVE FREQUENCIES

Figure 12

The user will punch the distribution number, in this case, 21, on a single card, and on the following card punch the values of the random variables and the associated cumulative relative frequencies. The next card will contain the number of the next distribution the user wishes to furnish, and the card following it the data pretaining to the distribution. MHSS will continue to read distributions in this manner until it encounters a blank card. A maximum of eight points from the cumulative distributions are allowed. The random variable is called X, and the cumulative relative frequency called P in the program. Therefore, for the J'th distribution, which the user assigned a number MHSS calls NDIS(J), the values X(J,1), P(J,1) to X(J,8), P(J,8) are read. P(J,1) must be equal to zero and P(J,8), or some other P(J,K), with K < 8, must be equal to unity. Finally when the blank card is encountered, MHSS will set KDIS equal to the number of user furnished distributions, and the input phase is completed.

Once the input phase has been completed, MHSS executes operations on the data to provide for more efficiency once the simulation begins. These operations are represented in Block 4 of Figure 8 entitled Establish Move-Equipment Linkages. When the input phase is completed, the computer has the data on the moves and equipment stored in the same manner as the user furnished it to MHSS. For example, the fourth move read in the input phase might be coded MV9 and require EQA and EQB. Assume EQA is the sixth piece of equipment on the equipment list and EQB is the tenth. If the user furnished code name MV9 was placed in the schedule, consider the problems that would occur when the time for the move was reached. First, MV9 would have to be compared with all the move codes until a comparison was encountered. In this example, four comparisons would be made. $JEQR1_4$ would be EQA and $JEQR2_4$ would be EQB. The equipment list would have to be searched to find EQA and EQB, to determine if these pieces of equipment are available to execute the move. $TEQAV_6$ is the tag for EQA which gives the time it will be available and $TEQAV_{10}$ is the tag for EQB. To avoid the time consuming checking of lists, MHSS will substitute the position on the equipment list for each piece of equipment required for a move. In the above example, $JEQR1_4$ would be set to 6 and $JEQR2_4$ would be set to 10. Then when the fourth move occurs, the variable $TEQAV_{JEQR1_4}$ would give the time the first piece of equipment required will be available, and $TEQAV_{JEQR2_4}$ would give the time for the second. The substitution of list position for code is made for all move and equipment codes. If MV9 had an optional move coded XV3, and XV3 was in the twentieth position of the move list, $MCØP_4$ would be set to 20. The blocking list is also altered, so that it will contain positions on the move list rather than move codes. Also during this phase the integrity of the data is checked. If a move has a following move that does not appear on the move list, for example, a message is printed informing the user of this fact, and the run is then terminated.

The next phase of the MHSS program is shown as Block 5 of Figure 8. This is the initialization phase. During this phase, the initial occurrences of the events are placed in the schedule. It might be well at this point to examine the scheduling technique used in MHSS. The schedule is a threaded list, which allows for rapid filing of data into the schedule, and also enables items to be quickly withdrawn. With a threaded list, a cell contains not only a piece of data, but also pointers that show where the next item on the list is located and where the preceding item on the list is found. Figure 13 shows the operation of the MHSS schedule. In Figure 13, a schedule capable of holding six events is shown. Each cell in the schedule has a flag associated with it (variable FLAG in the program), which determines if the cell is currently holding an event that is to take place sometime in the future. When the flag is zero, no event is currently being stored in its associated cell. In Figure 13A, there are five events stored. Cell 6 is currently empty. Each event has its event code and the time of its occurrence stored in the cell. (CODE and TM). MHSS constantly stores the cell number that contains the earliest event in the schedule (NST), and the cell number containing the last event in the schedule (NEN). In Figure 13A, event 25 is the first event to occur and is stored in cell 2. Thus, NST is equal to 2. Event 116, scheduled at 8:40 is the last event in the schedule and is stored in cell 3.

CELL	CODE	TIME	NEXT	PRECEDING	FLAG
1	17	8:30	5	4	1
2	25	8:10	4	0	1
3	116	8:40	0	5	1
4	16	8:25	1	2	1
5	29	8:35	3	1	1
6	--	--	-	-	0

Start Cell = 2 Finish Cell = 3 Last Cell Utilized = 5

A

CELL	CODE	TIME	NEXT	PRECEDING	FLAG
1	17	8:30	5	4	1
2	--	--	-	-	0
3	116	8:40	0	5	1
4	16	8:25	1	0	1
5	29	8:35	3	1	1
6	--	--	-	-	0

Start Cell = 4 Finish Cell = 3 Last Cell Utilized = 5

B

CELL	CODE	TIME	NEXT	PRECEDING	FLAG
1	17	8:30	5	4	1
2	--	--	-	-	0
3	116	8:40	6	5	1
4	16	8:25	1	0	1
5	29	8:35	3	1	1
6	52	9:00	0	3	1

Start Cell = 4 Finish Cell = 6 Last Cell Utilized = 5

C

MHSS SCHEDULE OPERATIONS

Figure 13

NEN, therefore, would be 3.

Stored along with the event code and its time in a schedule cell, is the cell number of the event that is to follow it, and the cell number of the event that precedes it (NX and JP). In Figure 13A, event 16 in cell 4 is followed by event 17 in cell 1 and preceded by event 25 in cell 2. Therefore, $NX_4 = 1$ and $JP_4 = 2$. Figure 13B shows the schedule after the first event has been removed. NST now equals 4 since event 16 at 8:25 is the next to occur. The flag for cell 2 has been set to zero, and this cell is now available for a new event to be stored. $JP_4 = 0$, since no event now precedes the event in cell 4.

Figure 13C shows the schedule after an event has been added. MHSS keeps track of the cell number last utilized by the schedule in the variable LWC. Whenever a new event is to be added to the schedule, LWC is increased by one and the event assigned to the cell whose number is the new value of LWC, provided LWC is not greater than the size of the schedule and the flag of cell number LWC is zero. In the example of Figure 13, LWC is equal to 5 in B. When a new event is to be added to the schedule, LWC is increased by one to six. The schedule is capable of storing six events, the flag of cell 6 is zero, therefore the event, event 52 in the example, and its time are stored in cell 6. Figure 13C shows the schedule after this addition. Since event 52 has a time of

9:00, it now is the last event in the schedule and NEN is set to 6. NX_3 is set to 6 and the addition of the event is completed. Suppose another event is now to be added to the schedule. Assume it is event 7 and its time of occurrence is 8:45. When LWC is increased by one to equal 7, MHSS determines that it must now start back at the beginning of the schedule cells to find one that is empty. It finds such a cell in cell 2 and assigns the event to that cell. Figure 14 shows the schedule after this assignment has been made. If at this point another attempt was made to add an event to the schedule, MHSS would find all cells filled and halt the simulation.

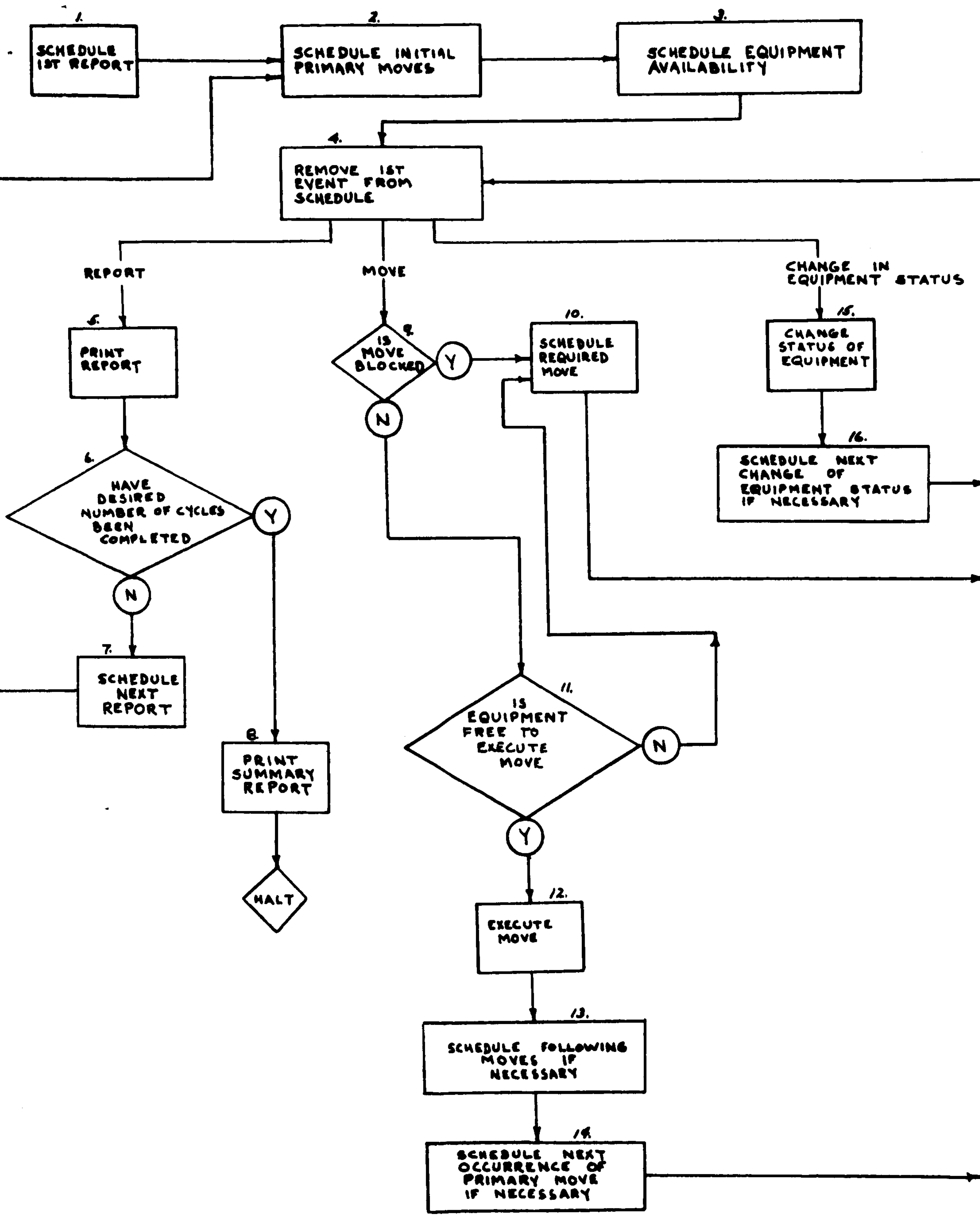
Cell	Code	Time	Next	Preceding	Flag
1	17	8:30	5	4	1
2	7	8:45	6	3	1
3	116	8:40	2	5	1
4	16	8:25	1	0	1
5	29	8:35	3	1	1
6	52	9:00	0	2	1

Start Cell 4 Finish Cell 6 Last Cell Utilized 2

FILLED MHSS SCHEDULE

Figure 14

Figure 15 is a flow chart of the operations required to add an event to the schedule. In the flow chart CIN is the code of the event to be added, TMIN the time the event



FLOW CHART FOR INPUT TO SCHEDULE OPERATIONS

Figure 15

is to occur, and NCEL is the number of cells in the schedule. The position on the move list is the code filed in the schedule for a move event. The position on the equipment list plus 5000 is the code used for the event where a piece of equipment is to become available to the system and the position on the equipment list plus 10,000 is the code used for the event where a piece of equipment is to become unavailable to the system. A report event is coded 15,000. Figure 16 gives a table of these codes.

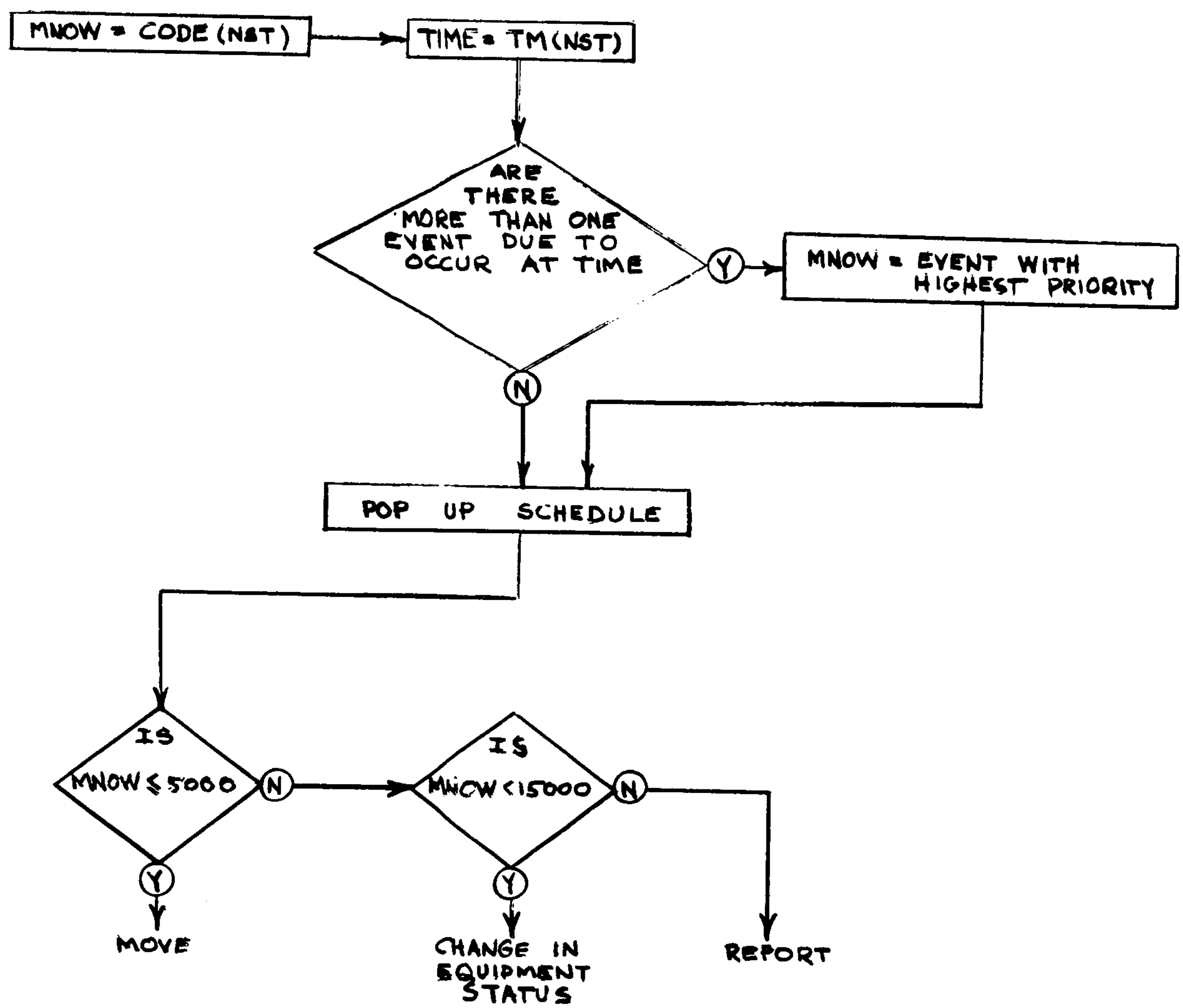
Range of Code	Event Type
$1 \leq \text{Code} \leq 5{,}000$	Move
$5001 \leq \text{Code} \leq 10{,}000$	Equipment becoming available
$10001 \leq \text{Code} < 15{,}000$	Equipment becoming unavailable
$\text{Code} = 15{,}000$	Report

EVENT CODES

Figure 16

In the program the statement CALL FILE (X,Y) will cause an event coded X to be filed in the schedule to occur at time Y. Subroutine FILE performs the operations of Figure 15. During the initialization phase, the initial occurrence of all primary moves, the report to occur at the end of the cycle, and the start of the equipment availability periods, are filed in the schedule. Various tallies and sums are also initially set to zero during this phase.

After initialization, the simulation begins. In Blocks 6 to 7 of Figure 8, the operations required to remove the next event from the schedule, and determine what it is are represented. These operations are shown in Figure 17. If the event is a change of equipment status, it is executed immediately. If the event is a report, the time of the following event is checked.



EVENT TYPE DETERMINATION

Figure 17

The time of the following event is $TM_{NX_{NST}}$. If this time is equal to TM_{NST}, then this following event will take precedence over the report since report events have lowest priority. All events that are to occur at the same time are checked so that the event which will be executed at that time will be the event with the highest priority. Change of equipment status first, moves second, and reports last. If two or more moves are to occur at the same time, the move with the highest user assigned priority will first be executed. A check is also made to determine if there will be a reversal of time in the simulation. If $TM_{NX_{NST}} < TM_{NST}$ it means the event following the first event in the schedule is scheduled earlier than the first event in the schedule. In this situation MHSS will print information concerning the condition of the schedule to aid in de-bugging and then stop. No attempt is made to unravel the condition, since it probably occurred as a result of error in the input data, and the worth of the simulation would be questionable if allowed to continue.

If the event is a change of equipment status, subroutine EQCHG(IN,TIME) is called. This subroutine is represented by Block 8 of Figure 8. The first argument IN, is the code of the event, and the second argument TIME, is the time of the event. If the equipment is becoming available to the system, then IN $\leq$ 10,000. The position on the equipment list of the equipment involved is then found by subtracting 5,000 from IN.

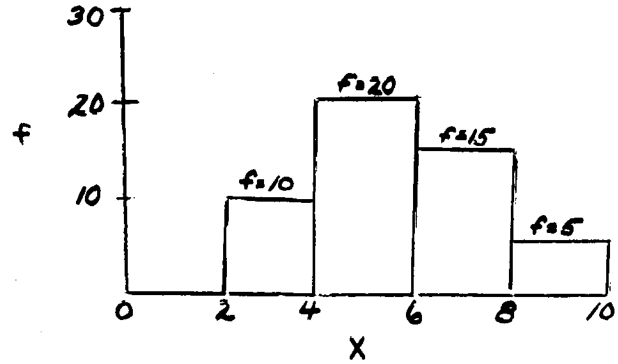
For this I'th piece of equipment TEQAV (I) is set to TIME. If the proportion of time the equipment is available to the system (PEQAV (I)) is 1.0, an event is added to the schedule to occur at the end of the availability period for the piece of equipment (TMEQN (I)). The code for the schedule would be I + 10,000. If PEQAV (I) < 1, MHSS must determine when the equipment will next become unavailable. The occurrences of these periods when the equipment becomes unavailable to the system are assumed to follow a Poisson distribution. The time interval between Poisson arrivals has a probability density function

$$(1) \qquad f(x) = \lambda e^{-\lambda x}$$

where λ is the mean arrival rate. To find the cumulative distribution function F(x) integrate from 0 to t and obtain

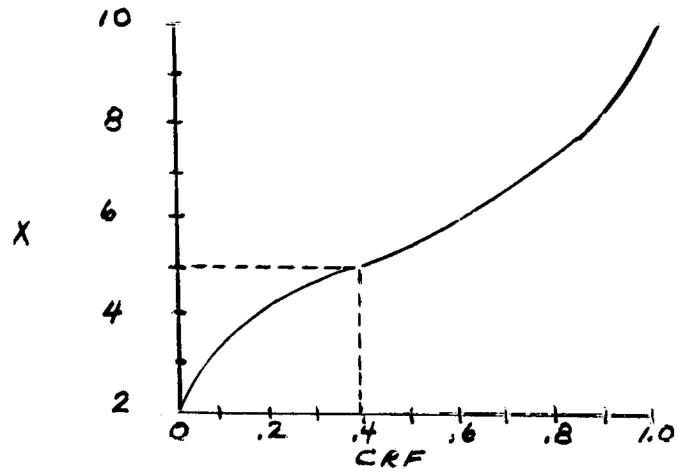
$$(2) \quad F(x) = \int_0^t \lambda e^{-\lambda x} dx = \lambda \left(\frac{e^{-\lambda x}}{-\lambda} \right. \Bigg|_0^t = -(e^{-\lambda t} - 1) = 1 - e^{-\lambda t}$$

Once a cumulative distribution function is obtained, it is an easy matter to simulate the universe from which the function was obtained. Assume a histogram and the approximation to the cumulative distribution function are as shown in Figure 18. If we sample at random from a uniform distribution between zero and unity and transform each value from this uniform distribution to a corresponding x value in Figure 18B, a histogram of the transformed values will look very much like the histogram in Figure 18A. For example, a value from the uniform distribution might be .42. This would be transformed to an x



HISTOGRAM

Figure 18A



CUMULATIVE RELATIVE FREQUENCY CURVE
Figure 18B

value of 5. We would expect approximately 40 per cent of the values from the uniform distribution to lie between .2 and .6. These values will be transformed to x values between 4 and 6. In the histogram of the original x values, 40 per cent of them were between 4 and 6. Returning to equation (2), where the cumulative distribution function of the time between Poisson arrivals is shown, this equation is set equal to U, a value of the cumulative probabilities.

$$U = 1 - e^{-\lambda t}$$

(3) or $$e^{-\lambda t} = 1 - U$$

After the natural log of both sides is taken.

(4) $$\log_e (e^{-\lambda t}) = \log_e (1 - U)$$

or $$-\lambda t = \log_e (1 - U)$$

(5) or $$t = -\frac{1}{\lambda} \log_e (1 - U)$$

Since U is a value of the cumulative probabilities, and these are the values that are going to be drawn from a uniform distribution, 1 - U is just the complement of U. There is no loss of generality, therefore, if the following expression is used instead of equation (5)

(6) $$t = -\frac{1}{\lambda} \log_e U$$

A FORTRAN statement to generate a random time for this distribution would be:

```
(7)        T = -1.0/A  * LOGE (RANDOM (NSEED) )
```

where A is the value of λ. For each piece of equipment whose proportion of time actually available to the system during the availability period is less than one, the user also must furnish information on the length of time the equipment is not available. From this data MHSS calculates the mean time the equipment is not available to the system. For many of the distributions, the mean is one of the furnished parameters. The mean number of times the equipment leaves the system during the availability period is calculated by:

(8) $$N = \frac{TAV - (PEQAV) \cdot (TAV)}{AVTGN}$$

where TAV = Length of the availability period

PEQAV = Proportion of time the equipment is actually available

AVTGN = Average length of time not available to the system

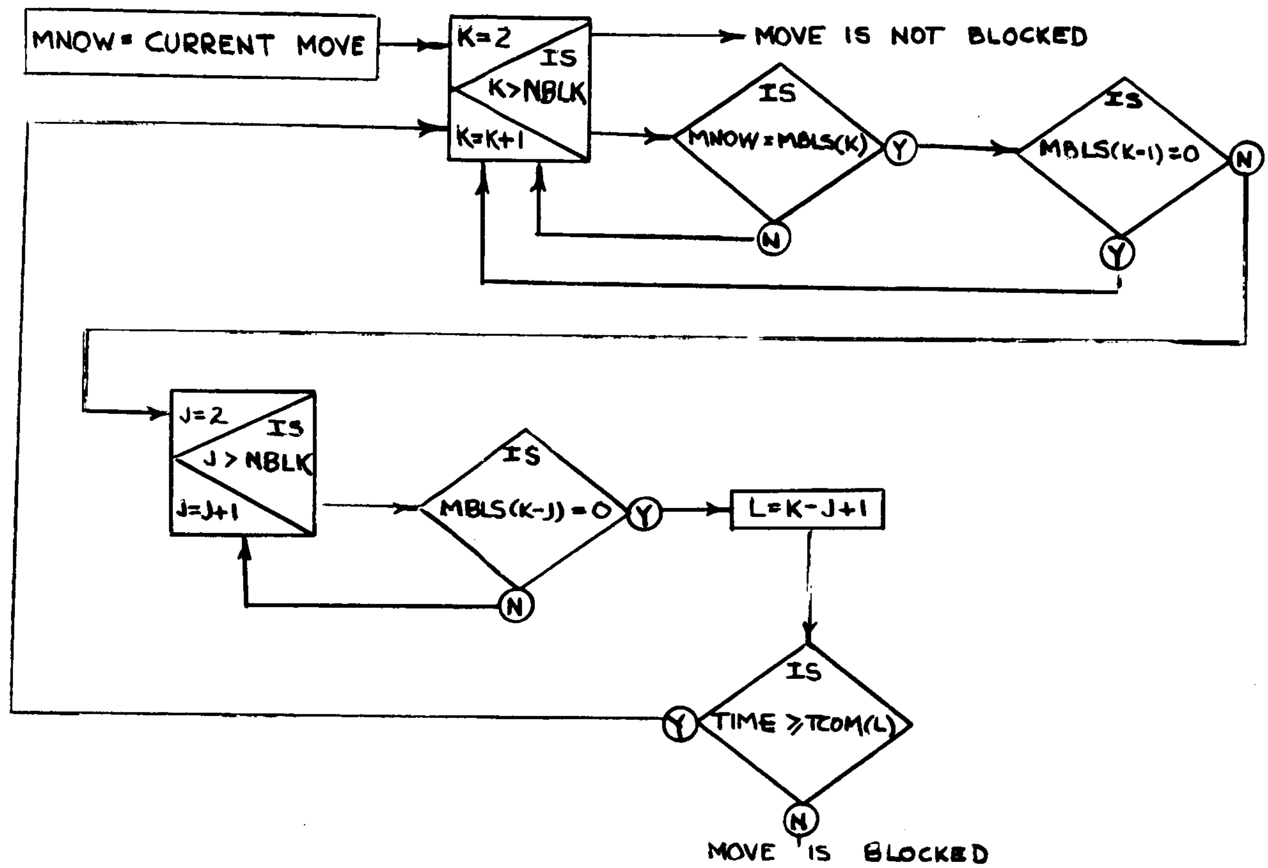
To calculate λ:

(9) $$\lambda = \frac{N}{TAV}$$

Each time a piece of equipment becomes available to the system, the time it next becomes unavailable is calculated using equations (7), (8), and (9). The code for the event that will be filed in the schedule will be the position of the equipment on the equipment list plus 10,000. When the event is a piece of equipment becoming unavailable to the system, detected by the code being between 10,000 and 15,000, MHSS must determine from the parameters on length of time not available, how long the piece of equipment will be gone. TEQAV for the piece of equipment is then set to the time the equipment will return An event, coded with the position on the equipment list plus 5,000, is added to the schedule to occur when the equipment will next become available. Each time a piece of equipment leaves the system, a variable for that particular piece of equipment ($TAWAY_I$) has the length of time the equipment will be gone added to it. Thus, at the end of a simulation cycle $TAWAY_I$ will hold the total amount of time a piece of equipment was unavailable to the system during the cycle. Variables

$TIDLE_I$ and $TWORK_I$ are used to contain the amounts of time the equipment was idle and working during the cycle. Whenever an event occurs for a piece of equipment to become unavailable to the system, and it is in the process of executing a move, deteced by TEQAV for the piece of equipment being greater than the current value of time, the event is filed back in the schedule, this time to occur at TEQAV. Once the change of equipment status has been attended to, MHSS returns to the schedule and removes the next event.

If the event is a move detected by code $\leq$ 5,000, MHSS first checks to see if the move is blocked. Block 12 of Figure 8 represents these instructions. Associated with each move is a variable $TCOM_I$, which gives the time the I'th move will be completed. If $TCOM_I \leq TIME$ (TIME is the current value of time), the move is not now in progress. MHSS will look at the blocking list to see if the current move appears on the list. If it finds the move on the list, it looks at the cell preceding the move to see if it is zero. If it is zero, the current move is itself a blocking move, and the remainder of the blocking list is checked. If it is not zero, the current move is a move that can be blocked. The blocking list is then checked in reverse from that point on until a zero is encountered. The move following the zero is the blocking move for the current move. TCOM is looked at for the blocking move, and if it is greater than TIME, the move is blocked. The flow chart for these operations is shown in Figure 19.



BLOCKING DETERMINATION

Figure 19

If the move is blocked, MHSS must decide if an optional move is to be initiated. The time until the current move can be initiated is $TCOM_J$ - TIME where J is the blocking move. If this is greater than the time the user specified the move could wait, rather than initiate an optional move, an optional move will be initiated. If the current move does not have an option, then the current move is put back into the schedule to occur at $TCOM_J$. If an optional move is to be initiated, this move is added to the schedule to occur at TIME. Therefore, any time blocking is encountered, a move will be added to the schedule. If it is an optional move that is to be added, it is scheduled to occur immediately. If no option has been specified by the user, or the option is not required, then the current move is added to the schedule to occur when the blocking is finished. These operations are represented by Block 13 of Figure 8.

If the move is not blocked, MHSS now determines if the required equipment is available to execute the move. This is shown in Block 14 of Figure 8. Each move can have up to three pieces of equipment; $JEQR1_I$, $JEQR2_I$, and $JEQR3_I$. If a move requires only a single piece of equipment, $JEQR2_I$ will be zero. MHSS must, therefore, look at $TEQAV_{JEQR1_I}$, $TEQAV_{JEQR2_I}$, and $TEQAV_{JEQR3_I}$ for all $JEQRK_I \neq 0$ $(K = 1,2,3)$ to determine if $TEQAV_{JEQRK_I} \leq TIME$. If this is true, all the equipment required for the move is available. If a piece of equipment is not available, the equipment list is checked to see if another piece of like equipment might be available. For example, consider the move list and the equipment list of Figure 20.

MOVE LIST

Position	Move Code	Equipment Required
1	MV1	2, 4
2	MV2	1
3	CR1	3, 2
4	CRA	1, 5
5	MV3	4
6	CRB	5

EQUIPMENT LIST

Position	Equipment Code	Time Available
1	EQA	9.05
2	EQB	8.55
3	EQ3	10.07
4	EQ3	9.02
5	EQ4	8.30

MOVE AND EQUIPMENT LISTS

Figure 20

Assume the current time (TIME) is equal to 9.20 and event 3 occurs. Since the code for the event is $\leq$ 5,000, the event is a move and it is the third event on the move list. In this case, the third event on the move list is coded CR1, and $JEQR1_3 = 3$ and $JEQR2_3 = 2$ are the pieces of equipment required for the move. This means the third and second pieces of equipment on the equipment list are required. These are EQ3 and

EQB respectively. $TEQAV_{JEQR1_3} = TEQAV_3 = 10.07$ and since TIME is now 9.20, this piece of equipment cannot now be utilized. However, MHSS will check the equipment list to see if there is another piece of equipment with the same code. It assumes all like equipment is segregated on the equipment list. Therefore, since the equipment required in the example is in the third position, it would check the fourth and second positions for like equipment codes, and if it found none, assume there were no other pieces of like equipment. In the example, the equipment in the fourth position is the same as the equipment required, and its time available, $TEQAV_4 = 9.02$, is less than TIME, so this piece of equipment will be utilized. $JEQR2_3 = 2$, and $TEQAV_2 = 8.55$, so the second piece of equipment required for CR1 is available. Since only two pieces were required, $JEQR3_3 = 0$. If all the equipment required for the move is not available, MHSS must again make the determination to schedule an optional move to occur immediately, or to postpone the current move until all the required equipment is available. The operation in Block 13 of Figure 8, therefore, will be executed.

Finally, when it is determined that the move can be executed, that is the move is not blocked and the required equipment is available, the execution of the move will take place. The length of time the move will take is furnished by subroutine ATIME (PAR1, PAR2, PAR3, TIME, RTM). As arguments this subroutine uses three parameters on the statistical distribution to be used, the current value of TIME, and the value it will return with, RTM, is the value for the time when the event will be concluded. For example, consider a move whose length of execution follows a normal distribution with mean = .55 and standard deviation = .10. The three parameters would be .55, .10, and 3. The code for a normal distribution being 3. If the current value of TIME = 10.00, and a sample from this distribution was .60, the value of RTM would be equal to 10.60. TCOM for the move, and the TEQAV variables for all the equipment required would be set to 10.60. It might be well to consider how subroutine ATIME generates values from various distributions.

<u>Normal</u>

The probability density function for a uniform distribution between 0 and 1 would be:

$$\text{pdf} = 1 \quad \text{for } 0 \leq x \leq 1$$

$$\text{pdf} = 0 \quad \text{elsewhere}$$

The mean of this uniform distribution can be calculated by

$$m = \int_0^1 x\, f(x)\, dx = \int_0^1 x\, dx = \frac{x^2}{2}\Bigg|_0^1 = \frac{1}{2}$$

and its variance by:

$$\sigma^2 = \int_0^1 (x - m)^2 f(x)\, dx = \int_0^1 x^2\, dx - \int_0^1 2xm\, dx + \int_0^1 m^2\, dx = \frac{x^3}{3}\Big|_0^1 - \frac{x^2}{2}\Big|_0^1 + \frac{1}{4}\, x\Big|_0^1$$

$$= \frac{1}{3} - \frac{1}{2} + \frac{1}{4} = \frac{1}{12}$$

From the central limit theorem, it is known that if a sample of $X_1, X_2, \ldots X_n$ items are taken from a distribution with mean = μ and variance σ^2, that as $n \to \infty$ the distribution of sample means will follow a normal distribution with mean = μ and the standard deviation = $\frac{\sigma}{\sqrt{n}}$ i.e. $N(\bar{X}, \mu, \frac{\sigma}{\sqrt{n}})$. These $\bar{X}$ values can be transformed to normal deviates by

$$(10) \qquad Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}}$$

Using equation 10, and sampling from a uniform distribution one can obtain

$$(11) \qquad Z = \frac{\dfrac{\sum_{i=1}^{n} X_i}{n} - \dfrac{1}{2}}{\sqrt{\dfrac{\frac{1}{12}}{n}}} = \left(\frac{\sum_{i=1}^{n} X_i}{n} - \frac{1}{2} \right) \sqrt{12n}$$

$$= \left(\sum_{i=1}^{n} X_i - \frac{n}{2} \right) \sqrt{\frac{12}{n}}$$

from the final form of euqation 11, if n = 12 it reduces to

$$(12) \qquad Z = \sum_{i=1}^{12} X_i - 6$$

Therefore, to generate a random normal deviate, all that is necessary is to sum twelve random variables from a uniform distribution between 0 and 1 and subtract 6. Once a random normal deviate has been obtained, equation (13) is used to transform the deviate to the desired distribution

$$(13) \qquad Y = M + Z*\sigma$$

where M and σ are the mean and standard deviation from the desired normal distribution. Figure 21 gives the FORTRAN instructions required:

```
        SUM = 0.0
        DO  301  I = 1, 12
301     SUM = SUM + RANDOM (NSEED)
        RTM = PAR1 + PAR2 * (SUM - 6.0) + TIME
        RETURN
```

Figure 21

Rectangular

If the desired distribution is to be rectangular, subroutine ATIME simply converts a random value from the uniform random number generator to the desired distribution. PAR1 is the minimum value and PAR2 is the maximum value for the first two calling arguments. The third argument, PAR3, is 1, the code for the rectangular distribution. The FORTRAN statements required to generate a RTM value from a rectangular distributor are shown in Figure 22.

```
Y = RANDOM(NSEED)
RTM = TIME + Y * (PAR2 - PAR1)
RETURN
```

Figure 22

EXPONENTIAL

The technique for generating random values from an exponential distribution was explained previously during the description of how changes in equipment status were handled. In that case it was assumed the equipment leaves the system during its availability period in a random manner, and the time between these departures followed an exponenti distribution. If an exponential distribution is desired for some other time interval, subroutine ATIME is utilized. In this case PAR1 is the mean of the distribution, and PAR2 is the minimum value. The code for the exponential distribution is 2 and is the third parameter. The exponential distribution assumes a possible range of values from 0 to . A graph of the function would have the shape as shown in Figure 23 where m is the mean.

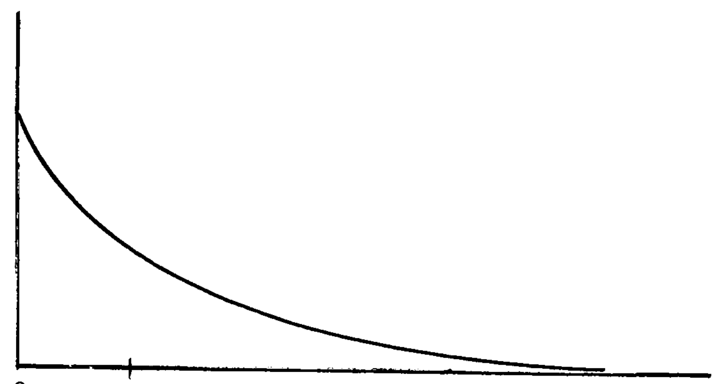


Figure 23

If the distribution has a non-zero minimum, as shown in Figure 24 where p is this minimum, it is necessary to adjust the mean

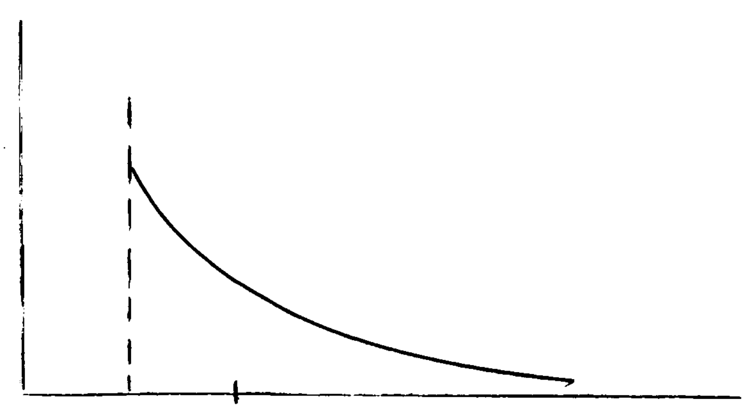


Figure 24

before generating values from the distribution. The adjusted mean is m - p and the distribution from which the random variable is drawn is shown in Figure 25.

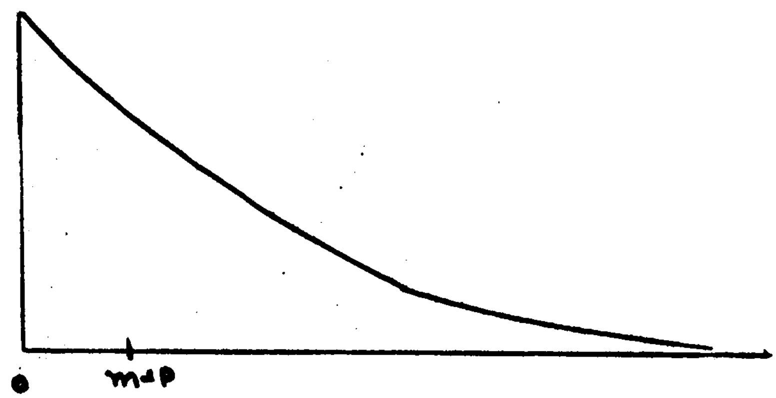


Figure 25

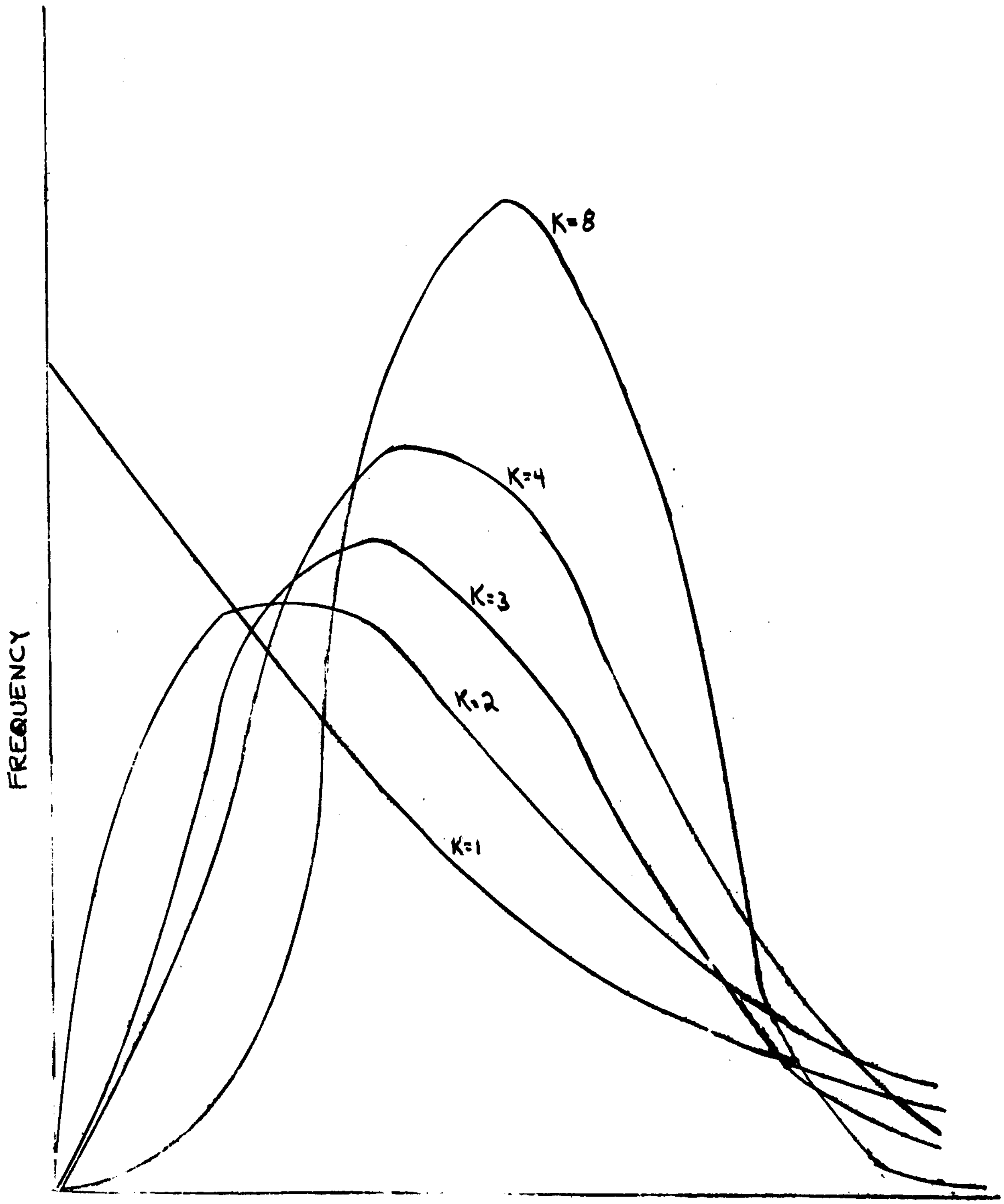
The random variable drawn is then adjusted to the desired distribution by adding p. The FORTRAN statements required are shown in Figure 26.

```
AV = PAR1 - PAR2
RTM = TIME + PAR1 - AV * ELOG (RANDOM(NSEED))
RETURN
```

Figure 26

<u>Erlang</u>

The Erlang distributions are a series of curves, each with a given shape parameter K. The curves for K = 1, 2, 3, 4, and 8 are shown in Figure 27. A random variable from an Erlang curve with shape parameter K is found by taking the mean of a



ERLANG CURVES

Figure 27

sample of K random variables from an exponential distribution. Therefore, with K = 1 the Erlang curve is actually an exponential distribution. As K gets large, the Erlang curve approaches the normal distribution as one would expect from the central limit theorem. The first three parameters in calling for a random variable from an Erlang distribution are: PAR1 = the mean; PAR2 = the minimum value; PAR3 = the shape parameter + 10. The FORTRAN statements to generate the random value are shown in Figure 28

```
            K = PAR3 - 10
            AK = K
            SUM = 0.0.
            AV = PAR 1 - PAR2
            DO  52  I = 1, K
52          S = S - AV * ELOG (RANDOM(NSEED))
            S = S/AK
            RTM = PAR2 + S + TIME
            RETURN
```

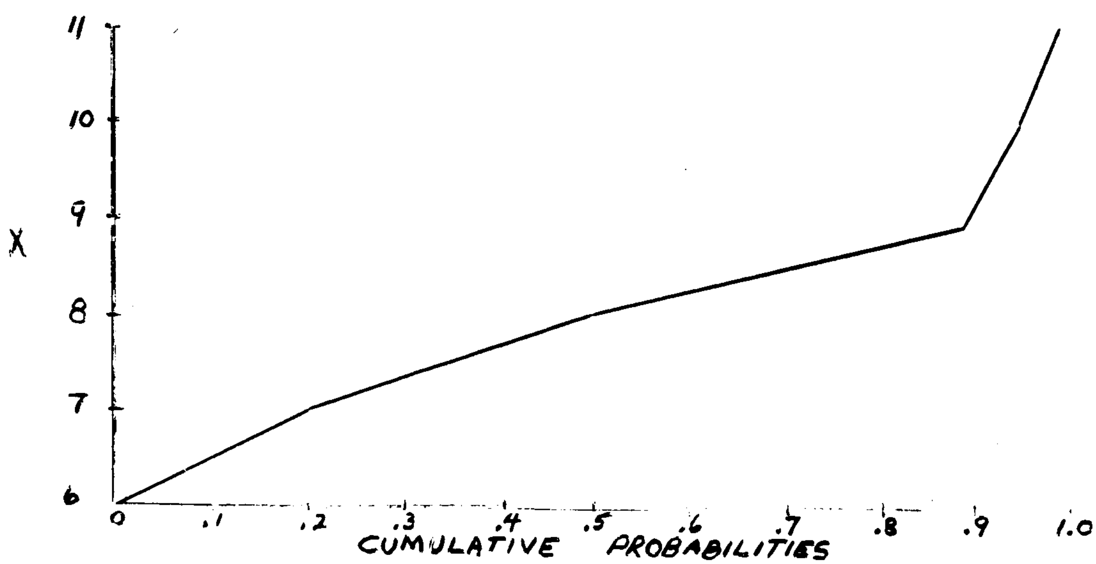
Figure 28

User Furnished Distributions

If the third parameter is greater than 20 in the calling arguments, subroutine ATIME recognizes the random variable is to come from a user furnished distribution. As explained in the discussion of the input techniques, user furnished distributions are read as coordinates of points from a cumulative distribution function. In obtaining a random variable from such a distribution, subroutine ATIME will obtain a random value between zero and one from the uniform distribution and then use linear interpolation to transform this value to the desired distribution. In effect, what is done is to approximate the cumulative distribution function with a series of straight line segments. For example, if the user furnished the data shown in Figure 29A, the approximation to the cumulative distribution function would be as shown in Figure 29B.

X	Cumulative Probability of X
6	0
7	.20
8	.50
9	.89
10	.95
11	1.00

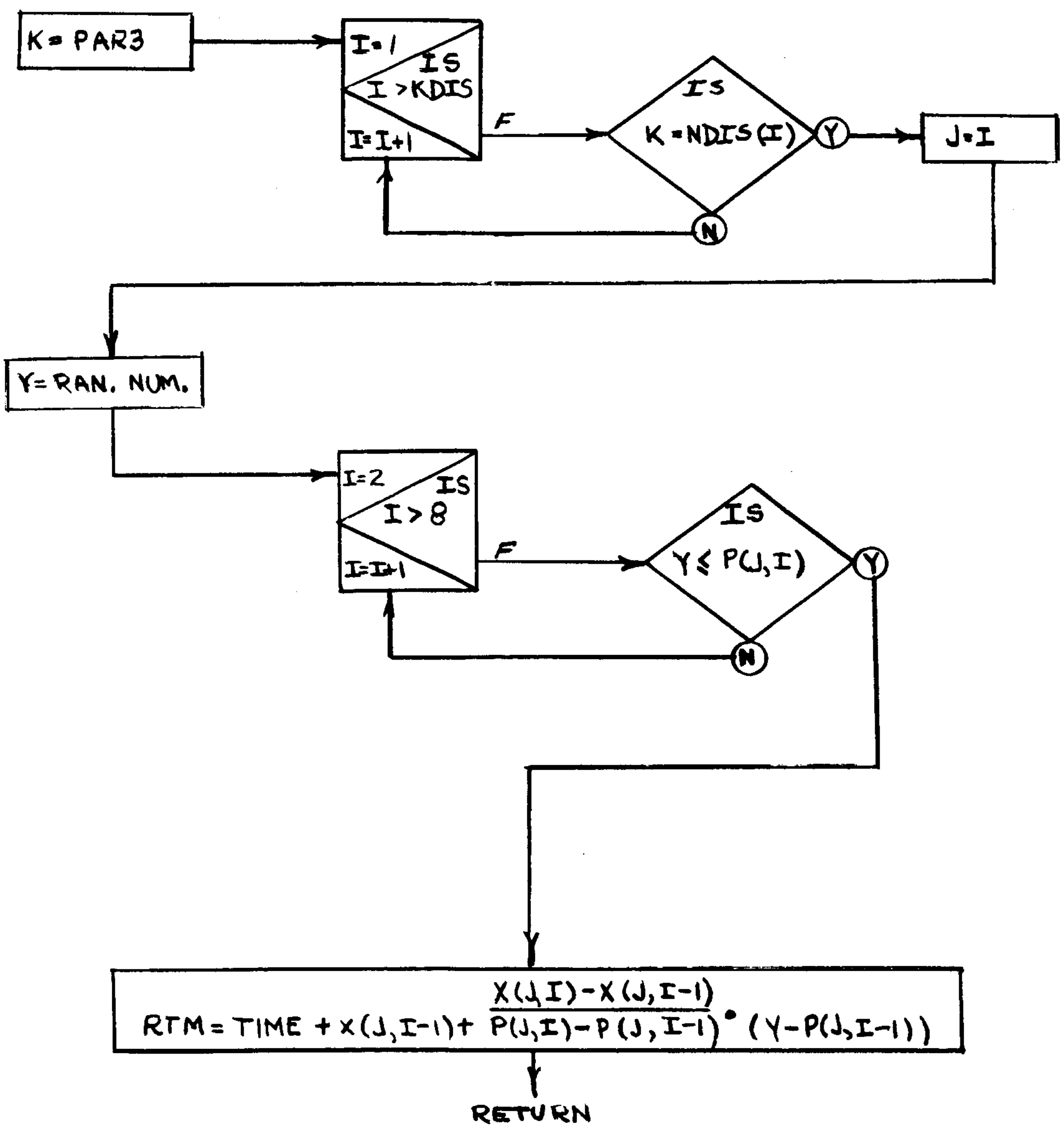
Figure 29A



USER DATA AND APPROXIMATION CURVE

Figure 29B

If the value drawn from the uniform distribution happened to be .35, this would be transformed to an X value of 7.5. The flow chart for these operations are shown in Figure 30.



FLOW CHART FOR CALCULATING VALUES
FROM USER FURNISHED DISTRIBUTIONS

Figure 30

KDIS is the number of user furnished distributions and $NDIS_i$ is the number assigned to the i'th distribution by the user. $X_{j,i}$ and $P_{j,i}$ are the i'th coordinates of the j'th distribution. The FORTRAN statements are shown in Figure 31.

```
      K = PAR3
      DO 45 I = 1, KDIS
      IF (K-NDIS(I)) 45, 55, 45
55    J = I
      GØ TØ 95
45    CONTINUE
95    Y = RANDOM(NSEED)
      DO 80 I = 2, 8
      IF (Y - P (J,I)) 60, 60, 79
60    RTM = TIME + X(J,I-1) + (J,I) - X(J,I-1)/
         (P(J,I) - P(J,I-1) * (Y-P(J,I-1)
      RETURN
79    IF (P(J,I)) 85, 85, 80
80    CONTINUE
85    PRINT 86, NDIS (J)
86    FORMAT (22H.BAD DISTRIBUTION.....,12)
      STØP
```

Figure 31

Constant

If the desired value is to be a constant, PAR1 is the constant value and PAR3 is 6, the code for the distribution. The FORTRAN statements therefore would be as shown in Figure 31.

```
RTM = PAR1 + TIME
RETURN
```

Figure 32

Zero

In certain situations the random variable might be desired to be aero. With PAR3 set to 9, this can be accomplished. The required FORTRAN statement would simply be RTM = TIME. Other distributions can be added to MHSS.

Distribution codes 4, 5, 7, and 10 are not used. Thus, if at some later time a user feels another distribution should be added, he can assign one of the four unused codes and insert the necessary instructions in subroutine ATIME. If code 4 is chosen, the instructions would begin at statement 400 in the subroutine, if 5 is chosen at statement 500, 7 at statement 700, and 10 at statement 1000. If more than four distributions are desired to be added, a change in the program can readily be made. This would require changing the coding scheme used for user furnished distributions. As it is now programmed, any distribution code over 20 is recognized as a user furnished distribution. This could be changed to 30 and then the codes from 21 to 30 would be available for built-in distributions.

After the time the move will be concluded has been determined, the variable TCOM for the move and the TEQAV variables for the required equipment are set to this finishing time. Tallies for the number of times the move occurred during the cycle, the total handling time the move required during the cycle, and the total work and idle time for the involved equipment are adjusted to include the data concerning the current move.

These variables in the program are

NOTMM = The number of times the move was made

TMMWT = The total handling time for the move during the cycle

TWORK = The total work time for a piece of equipment during a cycle

TIDLE = The total idle time for a piece of equipment during a cycle

In addition, if the move could not be executed when its demand first occurred, the variable WATMM for that move will have the length of time from the demand until execution began added to it. For example, a demand for a primary move could occur at 10.00. The move is blocked and the blocking will last until 10.06. The time rather than option is .10. In this situation the primary move will be put back into the schedule to occur at 10.06. At 10.06 the move again is attempted and its execution is started. MHSS keeps track of the time of the initial demand for the move, in this case 10.00, in the variable TMINT. When execution of the i'th move begins, TIME - $TMINT_i$ is the length of time the move had to wait. This wait interval is added to $WATMM_i$ which keeps a total of all the waiting time for the i'th move during the cycle. If the move to be executed is an optional move, the move that owned the optional move is the move that has the wait time changed. For example, assume MV1 is a primary move with OP1 an optional move for MV1. The user specified that MV1 is to wait .20 hour rather than execute the option. Assume a demand for MV1 occurred at 6.00. The required equipment for MV1 will not be available until 6.50. Therefore, an attempt will be made to execute the optional move, OP1. However, its required equipment will not be available until 6.10, and there are no other options. OP1 will begin execution at 6.10, and the .10 wait time between the original demand for the move and the start of execution will be added to the $WATMM_i$ associated with MV1.

After determining the length of time for the move, and satisfying the other operations required for its execution, MHSS moves on to the next step. It is now ready to add to the schedule the next occurrence of the move if it is a primary move, and also to add to the schedule any following moves that are to occur upon completion of the current move. This is shown in Block 16 of Figure 8. In scheduling the next occurrence of a primary move, subroutine ATIME is utilized and the calling arguments are the parameters the user furnished on the length of time between moves. It is to be remembered that MHSS assumes the length of time between moves is from demand to next demand. It is not the time between completion of a move and the next demand for the move. It is possible for a demand for a move to occur while the execution of the previous occurrence of the move is still in progress. If the current move is an optional move, the primary move that owns the option will be added to the schedule. The user does not furnish information on time between optional moves, since these moves only take place where the primary move that owns them are delayed.

Any following moves that are to occur upon the completion of the current move are also added to the schedule. The time from completion of the current move until the following move is to occur is determined again using subroutine ATIME and the parameters furnished by the user. Each move has two following moves associated with it. If more than two are desired, this can be accomplished using the following scheme.

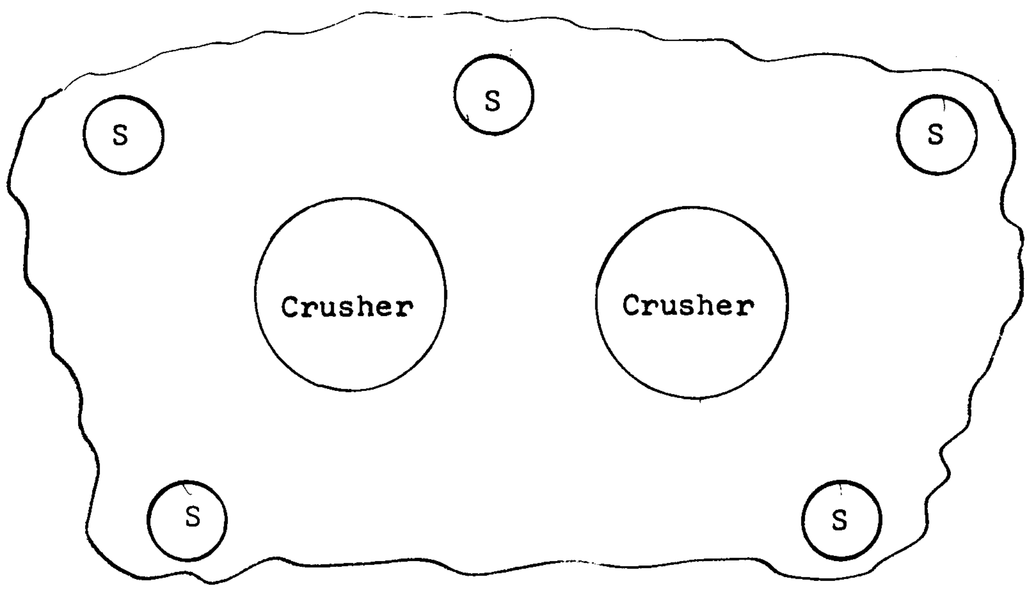
Assume MV1 is a primary move and four following moves are to occur upon its completion. Call these moves FL1, FL2, FL3, and FL4. As said before, MHSS only allows two following moves per move. The two following moves that would be associated with MV1 would be FL1 and a dummy move that could be called DM1. This dummy move requires no equipment and will never be on a blocking list. The length of time for execution of the dummy move will be zero. Upon the completion of MV1, DM1, and FL1, will be added to the schedule. Since DM1 requires no equipment, is never blocked, and also requires no time, it will be completed at the same time it started. DM1 will also have two following moves associated with it. One of them will be a dummy that require no equipment and no time. The second will be one of the legitimate following moves. The second dummy will have its two following moves, one of them a dummy and the other a legitimate move. This scheme will be continued until all the legitimate following moves have been assigned to the schedule. The following moves can be scheduled to occur immediately upon completion of the move they are to follow, or the time interval between completion and their time of occurrence can be specified by the user in the "time to following move" parameters. The user does not furnish data on time between moves for following moves, because, like optional moves a demand for their execution never occurs without the execution or demand of some other move. Once all the following moves have been assigned to the schedule, MHSS returns to the schedule and again removes the first event.

The last path of the program as shown in Figure 8 will now be discussed. This is the path of Blocks 9, 10, and 11 in the flow chart. Any time the current event is a report, event number = 15,000, MHSS will go to subroutine REPORT. There will be one report event per cycle, and if the user specified he desired to have a report printed at the end of each cycle, the report will be printed. He specifies this by setting IHOW on the first data card equal to zero. In some cases, the user may not wish these end of cycle reports and by setting IHOW ≠ 0 they will be suppressed. MHSS will still create a report event to occur at the end of the cycle since in addition to printing results, subroutine REPORT also performs bookkeeping duties that are required even if a report is not permited. Maximum and minimum values are kept for handling times, wait times, and number of moves per cycle for each move. At the end of each cycle it must be determined if new maximums or minimums have been established. Totals for handling times, wait times, and number of moves are also kept, so that averages can be calculated at the end of the simulation. Maximums, minimums, and totals are also kept for each piece of equipment. If the user specifies he wants the end of cycle reports averages to date are calculated and printed, otherwise averages are only calculated at the end of the simulation. All output instructions aside from error messages, are handled in subroutine REPORT, so that it would be an easy matter for a user to change the reports furnished by MHSS to suit his own needs.

IV. TESTING THE MODEL

In order to test the validity of the MHSS model, and to get opinions of those engaged in the making of decisions in this material handling area, MHSS was used in two industrial situations. The two applications were quite different, one the movement of ore to a crusher in an open pit mine, and the second the material handling function of fork lift trucks in a plant engaged in the manufacture of atomic energy equipment.

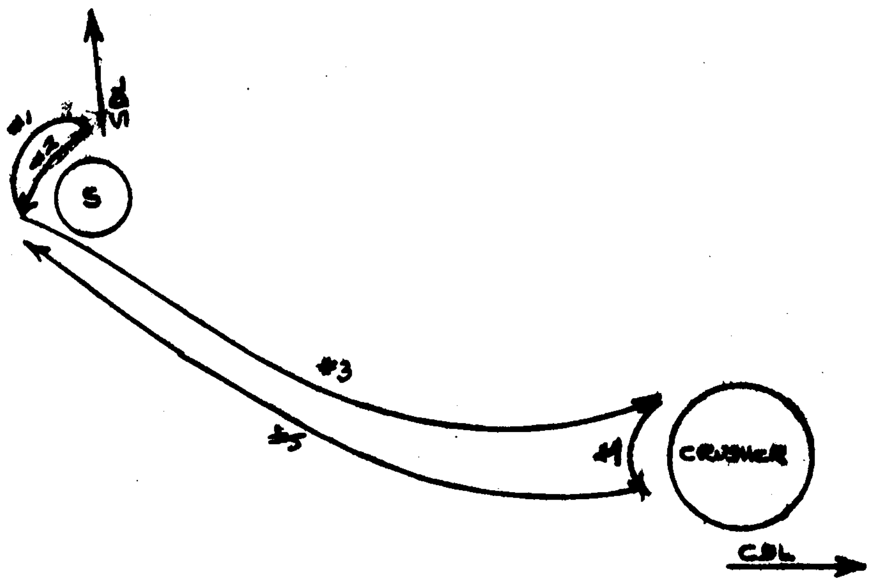
The first discussion will be of the iron ore open pit mining operation. In this operation large power shovels work at the face of the mine, loading trucks which then transport the ore to crushers where it is crushed. A map of the mine could be as shown in Figure 33. In the figure there are five shovels and two crushers. The position of the shovels and the



MAP OF AN OPEN PIT MINE

Figure 33

crushers change from time to time as the face of the mine changes. The main interest of management is the number and the types of trucks to assign to each of the shovels. By having too few a number of trucks assigned to a shovel the shovel will be idle a large percentage of the time waiting for a truck to load. Having an excess number of trucks assigned to a shovel can also be expensive if the trucks are not utilized to a great extent. The parameters in the problem do not remain constant. Three trucks might be quite adequate when the shovel is within one-half mile of the crusher, but the next day the shovel might be 3/4 of a mile from the crusher, and three trucks may only keep the shovel busy 50 per cent of the day. The grades along the routes the trucks must travel also have an impact as well as the distance of the routes. A shovel situated in such a location that the route from the shovel to the crusher is all up hill, would probably require more trucks than a shovel the same distance from the crusher but with a level route to traverse. The moves required to service a shovel are shown in schematic form in Figure 34. A description of each of these moves will follow.



SCHEMATIC DIAGRAM OF MINE MOVES

Figure 34

Move #1 - Spot Truck

This is the move required to position a truck next to the shovel so that it can be loaded. The shovel can do no loading on the truck involved in the move, or any other truck while this move is in progress. Therefore, this move requires a truck and the shovel, and can take place as soon as the shovel has completed loading another truck.

Move #2 - Load Truck

This is the move where the truck is actually receiving ore. It starts immediately upon completion of #1. The move requires a truck and the shovel.

Move #3 - Truck to Crusher

This is the move where the truck transports a load of ore to the crusher. The move starts immediately upon the completion of #2. It requires, of course, only one truck.

Move #4 - Spot and Dump

This is the move where the truck gets into position to dump and then dumps its load into the crusher. It is impossible for more than one truck to be executing this move at the same time, therefore, one truck and the crusher are the equipment involved in this move. The move begins immediately upon completion of #3.

Move #5 - Truck to Shovel

This is the move where the empty truck makes the trip back to the shovel. It travels the same route it came when it was loaded. There is, of course, only one truck involved in the move, and the move can begin immediately upon completion of #4.

SDL - Shovel Delay and Repair

From time to time during the day, short minor repairs and adjustments must be made on the shovel. There are also occasions when large rocks which interfere with the loading process have to be moved out of the way. These types of events were included in the move list, because data was available as to the length of time between occurrences, and the data indicated that these occurrences were not purely random. Had the occurrences been random, these times could have been accounted for, as times the equipment was unavailable to the system being simulated.

CDL - Crusher Dealy and Repair

As was the case with the shovel, short repairs and adjustments also are required with the crusher. It is also necessary to remove large rocks from the crusher on occasion. Data was also available on these crusher delays which indicated the times were not random.

There were four types of trucks available to service the shovel. These types varied as to capacity and speed. For convenience, the four truck types were labeled A, B, C, and D. Figure 35 gives a summary of the capacities of the four types and also the speed on the level with a full load. The truck manufacturers also furnished data on truck speeds on various grades. For example, for a Type A loaded truck on a grade > 3.0 per cent, the equation

(13) $$Y = .025 + \frac{.104}{7}(x)$$

gives the truck speed Y in hrs./mile where x is the per cent grade times 100. The grades can have a very significant effect on truck speed. For example Type A truck with a full load has a speed of 31.4 mph on the level, but going up a 7 per cent grade has a speed of only 7.7 mph. A 7 per cent grade was the maximum grade for any of the routes at the present time in the mine.

TYPE	CAPACITY IN TONS	SPEED IN MPH
A	78.8	31.4
B	60.6	23.4
C	42.7	22.6
D	34.8	24.3

TRUCK SPEEDS AND CAPACITIES

Figure 35

It was decided to simulate a shovel serviced by four trucks, one of each type. This was done because production figures were available on the #1 shovel in the mine, which was serviced by just this arrangement. Production figures from MHSS could then be compared with actual data. One crusher actually services more than one shovel, but dump times at the crusher are very short and a truck rarely has to wait for another truck before dumping their loads. Therefore, very little realism was lost by having the crusher service only one shovel. For each of the moves that involved a truck, the truck type and the move number were combined to form the move code used in the simulation. For example, A2 would be the move code used for loading a Type A truck. To also distinguish the shovel involved, the shovel number was added to the front of the code. Therefore, the code becomes 1A2 and means a Type A truck being loaded by shovel 1.

In this system, the only primary moves involved were the SDL and the CDL moves. All other moves were following moves. Once a truck is spotted at the shovel, it is loaded. After it is loaded, it immediately begins the trip to the crusher. The shovel becomes involved with the spotting of the next truck immediately after loading a truck. After a truck completes the trip to the crusher, the dump move immediately follows. After dumping, the truck makes the trip back to the shovel. Thus, every move is a following move and begins immediately after the move that preceded it is completed. In this situation, there still has to be a primary move to get the system moving.

Once the system is in operation, the completion of a loading move will start a spotting move, but what is needed is a way to trigger the first spot move in the morning. This can easily be done with a dummy primary move. This will require no equipment, no time, and the time between occurrences of this dummy move will also be zero. Therefore, it will occur at the very beginning of the simulation when TIME is equal to zero. It will have one following move which will be the spot move for a truck. Since this dummy move requires no time, the spot move will also be scheduled to occur at TIME = 0. Whenever a primary move is specified as having zero time between demands for the move, MHSS recognizes the move as a dummy and will not reschedule this move again. Therefore, the dummy primary move only will occur one time at the beginning of the simulation cycle and will perform its function of getting the system started. Management policy at the mine was to fill the trucks on a first in, first out basis. In other words, if a smaller truck is waiting for a load and a larger truck also arrives at the shovel, the smaller truck will be loaded before the larger truck because it was in the waiting line a longer period of time. Because of this policy, four dummy moves are required to get the system operational. The first dummy move has the spotting of the A truck as its following move, the second dummy move has the spotting of the B truck, and the third has the spotting of the C truck, and the fourth has the spotting of the D truck.

Figure 37 shows the input data for the moves. Notice the four dummy moves at the beginning of the list. Each one has a single following move which is a spot move. The spot moves then have their corresponding load moves as following moves. Each load move has a shovel to crusher move as its first following move, and a spot move for its specific type of truck as its second following move. Following the shovel to crusher

DUMMY MOVES

CODE	START	FIN	PAR1	PAR2 (MOVE TIMES)	PAR3	FOLLOWING MOVES
DM1	0.0	0.1			9	1A1
DM2	0.0	0.1			9	1B1
DM3	0.0	0.1			9	1C1
DM4	0.0	0.1			9	1D1

SPOT MOVES

CODE	START	FIN	PAR1	PAR2 (MOVE TIMES)	PAR3	FOLLOWING MOVES
1A1	0.0	8.0	.005	.002	12	1A2
1B1	0.0	8.0	.005	.002	15	1B2
1C1	0.0	8.0	.005	.002	12	1C2
1D1	0.0	8.0	.005	.002	15	1D2

LOAD MOVES

CODE	START	FIN	PAR1	PAR2 (MOVE TIMES)	PAR3	FOLLOWING MOVES
1A2	0.0	8.0			21	1A3, 1A1
1B2	0.0	8.0			22	1B3, 1B1
1C2	0.0	8.0			23	1C3, 1C1
1D2	0.0	8.0			24	1D3, 1D1

Figure 37

(continued on next page)

SHOVEL TO CRUSHER MOVES

CODE	START	FIN	MOVE TIMES PAR1	MOVE TIMES PAR2	MOVE TIMES PAR3	FOLLOWING MOVES
1A3	0.0	8.0	.064		6	1A4
1B3	0.0	8.0	.067		6	1B4
1C3	0.0	8.0	.069		6	1C4
1D3	0.0	8.0	.067		6	1D4

SPOT AND DUMP MOVES

CODE	START	FIN	MOVE TIMES PAR1	MOVE TIMES PAR2	MOVE TIMES PAR3	FOLLOWING MOVES
1A4	0.0	8.0	.026	.002	3	1A5
1B4	0.0	8.0	.025	.002	3	1B5
1C4	0.0	8.0	.024	.002	3	1C5
1D4	0.0	8.0	.023	.002	3	1D5

CRUSHER TO SHOVEL MOVES

CODE	START	FIN	MOVE TIMES PAR1	MOVE TIMES PAR2	MOVE TIMES PAR3	FOLLOWING MOVES
1A5	0.0	8.0	.030		6	
1B5	0.0	8.0	.050		6	
1C5	0.0	8.0	.056		6	
1D5	0.0	8.0	.052		6	

MOVE INPUT DATA FOR MINE SIMULATION

Figure 37

(continued from previous page)

move is the spot-dump move at the crusher. After dumping comes the crusher to shovel move and the cycle is completed. The times for the moves were furnished by the company and were gathered by work sampling and time studies at the mine, and by truck manufacturers tables on truck speeds. The data on the trucks for the first run is shown in Figure 38.

CODE	START TIME	FINISH TIME	PROPORTION OF TIME AVAILABLE
1A	0.0	8.0	1.0
1B	0.0	8.0	1.0
1C	0.0	8.0	1.0
1D	0.0	8.0	1.0

EQUIPMENT INPUT DATA FOR MINE SIMULATION
Figure 38

The results of the first run are shown on pages 86 through 98. The cycle length was set at eight hours and ten cycles were called for. For demonstration purposes, all of the end of cycle reports were printed and are shown. Referring to the summary report it can be seen that the Type A truck dumped an average of 30.30 loads into the crusher, the Type B truck dumped 28.10 loads, the Type C truck 27.60 loads, and the Type D truck 28.60 loads. These figures are found under the average number of moves column, for the 1A4, 1B4, 1C4, and 1D4 moves, which are the spot and dump at crusher moves. These load figures can be translated to total tonnage hauled by multiplying the average number of loads by the capacity for each truck and summating the products. This is done in Figure 39 and an average total tonnage per shift is 6264.3 tons.

TRUCK TYPE	CAPACITY		AVERAGE NO. OF LOADS		
A	78.8	x	30.30	=	2387.6
B	60.6	x	28.10	=	1702.9
C	42.7	x	27.60	=	1178.5
D	34.8	x	28.60	=	995.3
			Total tonnage	=	6264.3

Figure 39

The actual daily production figures for the shovel averaged 6,400 tons, so the MHSS model held very closely to the actual data in this situation. Referring again to the summary report, management can see the shovel has very little idle time during a shift, an average of .10 hours with a maximum of .18 hours and a minimum of .05 hours. The trucks, however, are idle from 2.47 hours for the Type B trick to 2.84 hours for the Type D truck. Management might want to see the tonnage with one of the trucks removed from service, for example, the Type D truck. The card that represents the 1D truck in the equipment list would be removed, and the rest of the input data would remain the same. Any of the moves that required the 1D truck in the simulation would not be executed since the truck required is not available. The results of the simulation are shown on page 99. The Type A truck dumped on the average 34.8 loads per cycle, the Type B

```
SYSTEM PARAMETERS
 1. MOVE CODE
 2. EQ. 1 REQUIRED
 3. EQ. 2 REQUIRED
 4. EQ. 3 REQUIRED
 5. TIME START
 6. TIME FINISHED
 7. MOVE 1ST PARAMETER
 8. MOVE 2ND PARAMETER
 9. MOVE DISTRIBUTION
10. TIME BETWEEN MOVES 1ST PARAMETER
11. TIME BETWEEN MOVES 2ND PARAMETER
12. TIME BETWEEN MOVES DISTRIBUTION
13. OPTIONAL MOVE
14. TIME BEFORE OPTION
15. 1ST FOLLOWING MOVE
16. TIME TO 1ST FOLLOWING MOVE 1ST PARAMETER
17. TIME TO 1ST FOLLOWING MOVE 2ND PARAMETER
18. TIME TO 1ST FOLLOWING MOVE DISTRIBUTION
19. 2ND FOLLOWING MOVE
20. TIME TO 2ND FOLLOWING MOVE 1ST PARAMETER
21. TIME TO 2ND FOLLOWING MOVE 2ND PARAMETER
22. TIME TO 2ND FOLLOWING MOVE DISTRIBUTION
23. MOVE PRIORITY
```

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
DM1				.000	.100	-.000	-.000	9	-.000	-.000	9		-.000	1A1	-.000	-.000	9		-.000	-.000	-0	9
DM2				.000	.100	-.000	-.000	9	-.000	-.000	9		-.000	1B1	-.000	-.000	9		-.000	-.000	-0	9
DM3				.000	.100	-.000	-.000	9	-.000	-.000	9		-.000	1C1	-.000	-.000	9		-.000	-.000	-0	9
DM4				.000	.100	-.000	-.000	9	-.000	-.000	9		-.000	1D1	-.000	-.000	9		-.000	-.000	-0	9
1A1	S1	1A		.0008	.000	.005	.002	12	-.000	-.000	-0		.000	1A2	.000	-.000	-0		-.000	-.000	-0	-0
1B1	S1	1B		.0008	.000	.005	.002	15	-.000	-.000	-0		.000	1B2	.000	-.000	-0		-.000	-.000	-0	-0
1C1	S1	1C		.0008	.000	.005	.002	12	-.000	-.000	-0		.000	1C2	.000	-.000	-0		-.000	-.000	-0	-0
1D1	S1	1D		.0008	.000	.005	.002	15	-.000	-.000	-0		-.000	1D2	.000	-.000	-0		-.000	-.000	-0	-0
1A2	S1	1A		.0008	.000	-.000	-.000	21	-.000	-.000	-0		-.000	1A3	.000	-.000	-0	1A1	-.000	-.000	-0	2
1B2	S1	1B		.0008	.000	-.000	-.000	22	-.000	-.000	-0		-.000	1B3	.000	-.000	-0	1B1	-.000	-.000	-0	2
1C2	S1	1C		.0008	.000	-.000	-.000	23	-.000	-.000	-0		-.000	1C3	.000	-.000	-0	1C1	-.000	-.000	-0	2
1D2	S1	1D		.0008	.000	-.000	-.000	24	-.000	-.000	-0		-.000	1D3	.000	-.000	-0	1D1	-.000	-.000	-0	2
1A3	1A			.0008	.000	.054	-.000	6	-.000	-.000	-0		-.000	1A4	.000	-.000	-0		-.000	-.000	-0	3
1B3	1B			.0008	.000	.067	-.000	6	-.000	-.000	-0		-.000	1B4	.000	-.000	-0		-.000	-.000	-0	3
1C3	1C			.0008	.000	.069	-.000	6	-.000	-.000	-0		-.000	1C4	.000	-.000	-0		-.000	-.000	-0	3
1D3	1D			.0008	.000	.067	-.000	6	-.000	-.000	-0		-.000	1D4	.000	-.000	-0		-.000	-.000	-0	3
1A4	1A	C		.0008	.000	.026	.002	3	-.000	-.000	-0		-.000	1A5	.000	-.000	-0		-.000	-.000	-0	4
1B4	1B	C		.0008	.000	.025	.002	3	-.000	-.000	-0		-.000	1B5	.000	-.000	-0		-.000	-.000	-0	4
1C4	1C	C		.0008	.000	.024	.002	3	-.000	-.000	-0		-.000	1C5	.000	-.000	-0		-.000	-.000	-0	4
1D4	1D	C		.0008	.000	.023	.002	3	-.000	-.000	-0		-.000	1D5	.000	-.000	-0		-.000	-.000	-0	4
1A5	1A			.0008	.000	.038	-.000	6	-.000	-.000	-0		-.000		-.000	-.000	-0		-.000	-.000	-0	5
1B5	1B			.0008	.000	.050	-.000	6	-.000	-.000	-0		-.000		-.000	-.000	-0		-.000	-.000	-0	5
1C5	1C			.0008	.000	.056	-.000	6	-.000	-.000	-0		-.000		-.000	-.000	-0		-.000	-.000	-0	5
1D5	1D			.0008	.000	.052	-.000	6	-.000	-.000	-0		-.000		-.000	-.000	-0		-.000	-.000	-0	5
CDL	C			.0008	.000	.208	.050	122	.080	-.000	2		-.000		-.000	-.000	-0		-.000	-.000	-0	6
SDL	S1			.0008	.000	.047	.011	11	.142	.032	12		-.000		-.000	-.000	-0		-.000	-.000	-0	6

EQ. CODE	TM. START	TM. FIN	PER. AV	TIME GENE PARAMETERS		
1A	.000	8.000	1.000	-.000	-.000	-0
1B	.000	8.000	1.000	-.000	-.000	-0
1C	.000	8.000	1.000	-.000	-.000	-0
1D	.000	8.000	1.000	-.000	-.000	-0
C	.000	8.000	1.000	-.000	-.000	-0
S1	.000	8.000	1.000	-.000	-.000	-0

NO EQUIP. OR OPTIONS DM1
NO EQUIP. OR OPTIONS DM2
NO EQUIP. OR OPTIONS DM3
NO EQUIP. OR OPTIONS DM4

REPORT A1 8.00 CYCLE NUMBER 1

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.93	32	.16	5.93	32.00	.16
1B1	6.11	31	.16	6.11	31.00	.16
1C1	6.77	30	.13	6.77	30.00	.13
1D1	6.67	30	.17	6.67	30.00	.17
1A2	.14	32	1.77	.14	32.00	1.77
1B2	.10	31	1.50	.10	31.00	1.50
1C2	.08	30	.97	.08	30.00	.97
1D2	.18	30	.88	.18	30.00	.88
1A3	.06	31	1.67	.06	31.00	1.67
1B3	.07	31	2.08	.07	31.00	2.08
1C3	.08	30	2.05	.08	30.00	2.05
1D3	.00	30	2.01	.00	30.00	2.01
1A4	1.19	31	.80	1.19	31.00	.80
1B4	.87	31	.77	.87	31.00	.77
1C4	.62	29	.71	.62	29.00	.71
1D4	.88	30	.68	.88	30.00	.68
1A5	.00	31	1.18	.00	31.00	1.18
1B5	.00	31	1.53	.00	31.00	1.53
1C5	.00	29	1.62	.00	29.00	1.62
1D5	.00	30	1.51	.00	30.00	1.51
CDL	.03	5	1.00	.03	5.00	1.00
SDL	1.23	52	2.08	1.23	52.00	2.08

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
1A	5.58	2.42	.00	5.58	2.42	.00
1B	6.04	1.96	.00	6.04	1.96	.00
1C	5.48	2.52	.00	5.48	2.52	.00
1D	5.25	2.75	.00	5.25	2.75	.00
C	3.95	4.05	.00	3.95	4.05	.00
S1	7.82	.18	.00	7.82	.18	.00

REPORT AT 8.00 CYCLE NUMBER 2

				AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.79	26	.14	5.86	29.00	.15
1B1	6.49	25	.13	6.30	28.00	.14
1C1	6.96	23	.12	6.87	26.50	.13
1D1	6.72	26	.13	6.70	28.00	.15
1A2	.42	26	1.55	.28	29.00	1.66
1B2	.19	25	1.20	.14	28.00	1.35
1C2	.10	23	.76	.09	26.50	.86
1D2	.26	26	.87	.22	28.00	.88
1A3	.00	26	1.40	.03	28.50	1.54
1B3	.15	24	1.61	.11	27.50	1.84
1C3	.00	23	1.57	.04	26.50	1.81
1D3	.23	26	1.69	.11	28.00	1.85
1A4	.79	26	.67	.99	28.50	.74
1B4	.57	24	.61	.77	27.50	.69
1C4	.60	22	.52	.61	25.50	.62
1D4	1.15	25	.57	1.01	27.50	.63
1A5	.00	26	.98	.00	28.50	1.08
1B5	.00	24	1.20	.00	27.50	1.37
1C5	.00	22	1.23	.00	25.50	1.43
1D5	.00	25	1.30	.00	27.50	1.40
CDL	.00	5	1.02	.02	5.00	1.01
SDL	1.29	52	2.99	1.26	52.00	2.54

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
1A	4.74	3.26	.00	5.16	2.84	.00
1B	4.75	3.25	.00	5.39	2.61	.00
1C	4.21	3.79	.00	4.85	3.15	.00
1D	4.56	3.44	.00	4.91	3.09	.00
C	3.40	4.60	.00	3.68	4.32	.00
S1	7.88	.12	.00	7.85	.15	.00

REPORT AT 8.CC CYCLE NUMBER 3

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.CC	1	.CC	.CC	1.CC	.00
CM2	.CC	1	.CC	.CC	1.0C	.00
CM3	.CC	1	.CC	.CC	1.0C	.00
CM4	.CC	1	.CC	.CC	1.0C	.00
1A1	6.CC	30	.16	5.9C	29.33	.15
1B1	6.34	25	.12	6.32	27.0C	.14
1C1	6.81	25	.13	6.85	26.0C	.13
1D1	6.83	28	.14	6.74	28.00	.14
1A2	.C3	30	1.7C	.2C	29.33	1.67
1B2	.C7	25	1.3C	.12	27.0C	1.33
1C2	.C5	25	.78	.C8	26.0C	.83
1D2	.C2	28	.95	.16	28.00	.90
1A3	.19	30	1.62	.C9	29.0C	1.57
1B3	.C7	25	1.67	.1C	26.67	1.79
1C3	.CC	25	1.72	.C3	26.0C	1.78
1D3	.CC	28	1.88	.C8	28.00	1.86
1A4	.49	30	.79	.82	29.0C	.75
1B4	.3C	25	.63	.61	26.67	.67
1C4	.29	25	.6C	.50	25.33	.61
1D4	.1C	28	.62	.71	27.67	.62
1A5	.CC	30	1.13	.CC	29.00	1.10
1B5	.CC	25	1.25	.CC	26.67	1.33
1C5	.CC	25	1.4C	.CC	25.33	1.42
1D5	.CC	27	1.4C	.CC	27.33	1.40
CDL	.C8	6	.81	.C4	5.33	.94
SDL	1.19	48	2.63	1.24	50.67	2.57

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
1A	5.4C	2.60	.CC	5.24	2.76	.CC
1B	4.97	3.C3	.CC	5.25	2.75	.CC
1C	4.64	3.36	.CC	4.78	3.22	.CC
1D	4.98	3.C2	.CC	4.93	3.C7	.CC
C	3.44	4.56	.CC	3.6C	4.4C	.CC
S1	7.9C	.1C	.CC	7.87	.13	.CC

REPORT AT MOVE CODE	8.00 WAIT TIME	CYCLE NUMBER 4 NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.85	31	.15	5.89	29.75	.15
1B1	6.57	23	.14	6.38	27.25	.14
1C1	6.71	27	.13	6.81	26.25	.13
1D1	6.76	29	.15	6.74	28.00	.15
1A2	.08	31	1.89	.17	29.75	1.73
1B2	.00	28	1.29	.09	27.25	1.32
1C2	.00	27	.95	.06	26.25	.86
1D2	.00	28	.93	.12	28.00	.91
1A3	.06	31	1.65	.08	29.50	1.59
1B3	.00	27	1.81	.07	26.75	1.79
1C3	.16	27	1.86	.06	26.25	1.80
1D3	.15	28	1.88	.09	28.00	1.86
1A4	.48	30	.80	.74	29.25	.77
1B4	.64	27	.65	.62	26.75	.66
1C4	.40	27	.66	.48	25.75	.62
1D4	.66	28	.65	.70	27.75	.63
1A5	.00	30	1.14	.00	29.25	1.11
1B5	.00	27	1.35	.00	26.75	1.33
1C5	.00	27	1.51	.00	25.75	1.44
1D5	.00	28	1.46	.00	27.50	1.42
CDL	.23	4	.65	.04	5.00	.87
SDL	1.39	48	2.31	1.28	50.00	2.50

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
1A	5.63	2.37	.00	5.34	2.66	.00
1B	5.23	2.77	.00	5.25	2.75	.00
1C	5.12	2.88	.00	4.86	3.14	.00
1D	5.07	2.93	.00	4.97	3.03	.00
C	3.41	4.59	.00	3.55	4.45	.00
SI	7.95	.05	.00	7.89	.11	.00

REPORT AT	8.00	CYCLE NUMBER 5		AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.89	33	.17	5.89	30.40	.16
1B1	6.18	30	.16	6.34	27.80	.14
1C1	6.72	29	.13	6.79	26.80	.13
1D1	6.48	29	.14	6.69	28.20	.14
1A2	.00	33	1.81	.13	30.40	1.74
1B2	.12	30	1.47	.10	27.80	1.35
1C2	.08	29	.88	.06	26.80	.87
1D2	.13	29	1.00	.12	28.20	.93
1A3	.07	33	1.78	.08	30.20	1.63
1B3	.00	30	2.01	.06	27.40	1.84
1C3	.00	29	2.00	.05	26.80	1.84
1D3	.00	29	1.94	.08	28.20	1.88
1A4	.51	33	.86	.69	30.00	.78
1B4	.42	30	.72	.58	27.40	.68
1C4	.56	29	.70	.49	26.40	.64
1D4	.80	29	.68	.72	28.00	.64
1A5	.00	33	1.25	.00	30.00	1.14
1B5	.00	29	1.45	.00	27.20	1.36
1C5	.00	29	1.62	.00	26.40	1.48
1D5	.00	29	1.51	.00	27.80	1.44
CDL	.05	4	.64	.04	4.80	.82
SDL	1.32	49	2.17	1.28	49.80	2.44

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
1A	5.88	2.12	.00	5.45	2.55	.00
1B	5.81	2.19	.00	5.36	2.64	.00
1C	5.34	2.66	.00	4.96	3.04	.00
1D	5.26	2.74	.00	5.02	2.98	.00
C	3.60	4.40	.00	3.56	4.44	.00
S1	7.93	.07	.00	7.89	.11	.00

REPORT AT	8.00	CYCLE NUMBER 6		AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.69	31	.15	5.86	30.50	.15
1B1	6.41	30	.17	6.35	28.17	.15
1C1	6.51	29	.15	6.75	27.17	.13
1D1	6.72	29	.15	6.70	28.33	.14
1A2	.40	31	1.66	.18	30.50	1.73
1B2	.00	30	1.37	.08	28.17	1.36
1C2	.24	29	.96	.09	27.17	.88
1D2	.00	29	.94	.10	28.33	.93
1A3	.00	31	1.67	.06	30.33	1.63
1B3	.00	30	1.98	.05	27.83	1.86
1C3	.08	29	2.00	.05	27.17	1.87
1D3	.00	29	1.94	.06	28.33	1.89
1A4	.10	31	.82	.59	30.17	.79
1B4	.14	29	.71	.51	27.67	.68
1C4	.32	29	.69	.46	26.83	.65
1D4	.22	29	.67	.63	28.17	.64
1A5	.00	31	1.16	.00	30.17	1.14
1B5	.00	29	1.45	.00	27.50	1.37
1C5	.00	29	1.61	.00	26.83	1.50
1D5	.00	29	1.51	.00	28.00	1.45
CDL	.00	2	.22	.03	4.33	.72
SDL	1.22	49	2.33	1.27	49.67	2.42

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
1A	5.45	2.55	.00	5.45	2.55	.00
1B	5.69	2.31	.00	5.42	2.58	.00
1C	5.41	2.59	.00	5.03	2.97	.00
1D	5.21	2.79	.00	5.06	2.94	.00
C	3.10	4.90	.00	3.48	4.52	.00
S1	7.89	.11	.00	7.89	.11	.00

REPORT AT 8.00 CYCLE NUMBER 7

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	5.84	31	.14	5.86	30.57	.15
1B1	6.13	29	.15	6.32	26.29	.15
1C1	6.85	30	.14	6.76	27.57	.13
1D1	6.60	31	.15	6.68	28.71	.15
1A2	.03	31	1.85	.16	30.57	1.75
1B2	.15	29	1.40	.09	28.29	1.36
1C2	.00	30	.95	.08	27.57	.89
1D2	.00	31	1.03	.09	28.71	.94
1A3	.00	31	1.67	.06	30.43	1.64
1B3	.00	29	1.94	.04	28.00	1.87
1C3	.00	30	2.05	.05	27.57	1.90
1D3	.07	31	2.08	.06	28.71	1.92
1A4	.39	31	.81	.57	30.29	.79
1B4	.44	29	.73	.50	27.86	.69
1C4	.60	29	.69	.48	27.14	.65
1D4	.32	31	.72	.59	28.57	.65
1A5	.00	31	1.18	.00	30.29	1.15
1B5	.00	29	1.45	.00	27.71	1.38
1C5	.00	29	1.62	.00	27.14	1.52
1D5	.00	31	1.61	.00	28.43	1.47
C0L	.03	4	.66	.03	4.29	.71
S0L	1.17	45	2.08	1.26	49.00	2.37

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
1A	5.65	2.35	.00	5.48	2.52	.00
1B	5.68	2.32	.00	5.45	2.55	.00
1C	5.46	2.54	.00	5.09	2.91	.00
1D	5.59	2.41	.00	5.13	2.87	.00
C	3.62	4.38	.00	3.50	4.50	.00
S1	7.89	.11	.00	7.89	.11	.00

REPORT AT 8.00 CYCLE NUMBER 8

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
DM1	.00	1	.00	.00	1.00	.00
DM2	.00	1	.00	.00	1.00	.00
DM3	.00	1	.00	.00	1.00	.00
DM4	.00	1	.00	.00	1.00	.00
1A1	5.77	32	.15	5.85	30.75	.15
1B1	6.25	31	.15	6.31	28.63	.15
1C1	6.59	30	.15	6.74	27.88	.14
1D1	6.67	30	.16	6.68	28.88	.15
1A2	.21	32	1.87	.16	30.75	1.76
1B2	.00	31	1.61	.08	28.63	1.39
1C2	.12	30	.98	.08	27.88	.90
1D2	.07	30	1.04	.08	28.88	.96
1A3	.13	31	1.67	.06	30.50	1.64
1B3	.00	31	2.01	.04	28.38	1.89
1C3	.00	30	2.07	.04	27.88	1.92
1D3	.00	30	2.01	.06	28.88	1.93
1A4	.33	31	.80	.54	30.38	.79
1B4	.06	30	.75	.45	28.13	.70
1C4	.10	30	.72	.44	27.50	.66
1D4	.01	29	.67	.52	28.63	.66
1A5	.00	31	1.18	.00	30.38	1.15
1B5	.00	30	1.50	.00	28.00	1.40
1C5	.00	30	1.68	.00	27.50	1.54
1D5	.00	29	1.51	.00	28.50	1.48
COL	.04	4	.40	.03	4.25	.67
SDL	.86	40	1.82	1.21	47.88	2.30

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
1A	5.67	2.33	.00	5.50	2.50	.00
1B	6.01	1.99	.00	5.52	2.48	.00
1C	5.61	2.39	.00	5.16	2.84	.00
1D	5.38	2.62	.00	5.16	2.84	.00
C	3.34	4.66	.00	3.48	4.52	.00
S1	7.92	.08	.00	7.90	.10	.00

REPORT AT 8.00 CYCLE NUMBER 9 AVERAGES TO DATE

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
CM1	.00	1	.00	.00	1.00	.00
CM2	.00	1	.00	.00	1.00	.00
CM3	.00	1	.00	.00	1.00	.00
CM4	.00	1	.00	.00	1.00	.00
1A1	6.22	29	.15	5.89	30.56	.15
1B1	6.01	29	.16	6.28	28.67	.15
1C1	6.72	28	.14	6.74	27.89	.14
1D1	6.14	29	.15	6.62	28.89	.15
1A2	.04	29	1.52	.15	30.56	1.73
1B2	.48	29	1.35	.12	28.67	1.39
1C2	.06	28	.96	.08	27.89	.91
1D2	.21	29	1.03	.10	28.89	.96
1A3	.00	29	1.57	.06	30.33	1.64
1B3	.07	28	1.88	.04	28.33	1.89
1C3	.00	28	1.93	.04	27.89	1.92
1D3	.23	29	1.94	.08	28.89	1.93
1A4	1.25	29	.72	.61	30.22	.79
1B4	.86	28	.72	.49	28.11	.70
1C4	1.27	28	.67	.53	27.56	.66
1D4	1.66	29	.65	.64	28.67	.66
1A5	.00	28	1.06	.00	30.11	1.14
1B5	.00	28	1.40	.00	28.00	1.40
1C5	.00	28	1.54	.00	27.56	1.54
1D5	.00	29	1.51	.00	28.56	1.48
CDL	.25	6	1.37	.06	4.44	.75
SDL	1.11	50	2.47	1.20	48.11	2.32

AVERAGES TO DATE

EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
1A	5.03	2.97	.00	5.45	2.55	.00
1B	5.50	2.50	.00	5.52	2.48	.00
1C	5.24	2.76	.00	5.17	2.83	.00
1D	5.28	2.72	.00	5.18	2.82	.00
C	4.13	3.87	.00	3.55	4.45	.00
S1	7.93	.07	.00	7.90	.10	.00

REPORT AT 8.00 CYCLE NUMBER 10

				AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
DM1	.00	1	.00	.00	1.00	.00
DM2	.00	1	.00	.00	1.00	.00
DM3	.00	1	.00	.00	1.00	.00
DM4	.00	1	.00	.00	1.00	.00
1A1	6.12	31	.15	5.91	30.60	.15
1B1	6.33	29	.14	6.28	28.70	.15
1C1	6.65	28	.14	6.73	27.90	.14
1D1	6.62	28	.13	6.62	28.80	.15
1A2	.00	31	1.61	.14	30.60	1.72
1B2	.00	29	1.48	.11	28.70	1.40
1C2	.00	28	.98	.07	27.90	.92
1D2	.03	28	.95	.09	28.80	.96
1A3	.06	31	1.67	.06	30.40	1.64
1B3	.15	29	1.93	.05	28.40	1.89
1C3	.00	28	1.93	.03	27.90	1.92
1D3	.00	28	1.88	.07	28.80	1.92
1A4	.28	31	.80	.58	30.30	.79
1B4	.48	28	.70	.49	28.10	.70
1C4	.70	28	.67	.55	27.60	.66
1D4	.40	28	.64	.62	28.60	.65
1A5	.00	31	1.18	.00	30.20	1.14
1B5	.00	28	1.40	.00	28.00	1.40
1C5	.00	28	1.57	.00	27.60	1.54
1D5	.00	28	1.46	.00	28.50	1.48
CDL	.00	2	.45	.05	4.20	.72
SDL	1.30	46	2.29	1.21	47.90	2.32

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
1A	5.41	2.59	.00	5.44	2.56	.00
1B	5.64	2.36	.00	5.53	2.47	.00
1C	5.28	2.72	.00	5.18	2.82	.00
1D	5.06	2.94	.00	5.16	2.84	.00
C	3.26	4.74	.00	3.53	4.47	.00
S1	7.87	.13	.00	7.90	.10	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HAND. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
DM1	.00	1.00	.00	.00	.00	1	1	.00	.00
DM2	.00	1.00	.00	.00	.00	1	1	.00	.00
DM3	.00	1.00	.00	.00	.00	1	1	.00	.00
DM4	.00	1.00	.00	.00	.00	1	1	.00	.00
1A1	5.91	30.60	.15	6.22	5.93	33	26	.17	.14
1B1	6.28	28.70	.15	6.57	6.11	31	25	.17	.12
1C1	6.73	27.90	.14	6.96	6.77	30	23	.15	.12
1D1	6.62	28.80	.15	6.83	6.67	31	26	.17	.13
1A2	.14	30.60	1.72	.42	.14	33	26	1.89	1.52
1B2	.11	28.70	1.40	.48	.10	31	25	1.61	1.20
1C2	.07	27.90	.92	.24	.08	30	23	.98	.76
1D2	.09	28.80	.96	.26	.18	31	26	1.04	.87
1A3	.06	30.40	1.64	.19	.06	33	26	1.78	1.40
1B3	.05	28.40	1.89	.15	.07	31	24	2.08	1.61
1C3	.03	27.90	1.92	.16	.08	30	23	2.07	1.57
1D3	.07	28.80	1.92	.23	.00	31	26	2.08	1.69
1A4	.58	30.30	.79	1.25	1.19	33	26	.86	.67
1B4	.49	28.10	.70	.88	.87	31	24	.77	.61
1C4	.55	27.60	.66	1.27	.62	30	22	.72	.52
1D4	.62	28.60	.65	1.66	.88	31	25	.72	.57
1A5	.00	30.20	1.14	.00	.00	33	26	1.25	.98
1B5	.00	28.00	1.40	.00	.00	31	24	1.53	1.20
1C5	.00	27.60	1.54	.00	.00	30	22	1.68	1.23
1D5	.00	28.50	1.48	.00	.00	31	25	1.61	1.30
CDL	.05	4.20	.72	.25	.03	6	2	1.37	.22
SDL	1.21	47.90	2.32	1.39	1.23	52	40	2.99	1.82

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
1A	5.44	2.56	.00	5.88	4.74	3.26	2.12	.00	.00
1B	5.53	2.47	.00	6.04	4.75	3.25	1.96	.00	.00
1C	5.18	2.82	.00	5.61	4.21	3.79	2.39	.00	.00
1D	5.16	2.84	.00	5.59	4.56	3.44	2.41	.00	.00
C	3.53	4.47	.00	4.13	3.10	4.90	3.87	.00	.00
S1	7.90	.10	.00	7.95	7.82	.18	.05	.00	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HANC. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
CM1	.00	1.00	.00	.00	.00	1	1	.00	.00
CM2	.00	1.00	.00	.00	.00	1	1	.00	.00
DM3	.00	1.00	.00	.00	.00	1	1	.00	.00
CM4	.00	1.00	.00	.00	.00	1	1	.00	.00
1A1	5.63	35.50	.18	5.82	5.75	38	32	.20	.16
1B1	6.12	33.50	.17	6.39	6.05	36	30	.19	.15
1C1	6.58	32.10	.16	6.74	6.46	34	29	.19	.13
1D1	.00	.00	.00	.00	.00	0	0	.00	.00
1A2	.10	35.50	2.04	.31	.00	38	32	2.27	1.82
1B2	.07	33.40	1.59	.21	.08	36	30	1.82	1.43
1C2	.10	32.10	1.04	.30	.11	34	29	1.10	.94
1D2	.00	.00	.00	.00	.00	0	0	.00	.00
1A3	.11	35.30	1.90	.37	.19	38	31	2.01	1.67
1B3	.11	33.10	2.22	.38	.00	36	29	2.41	1.94
1C3	.09	32.10	2.20	.32	.32	34	29	2.35	2.00
1D3	.00	.00	.00	.00	.00	0	0	.00	.00
1A4	.77	34.80	.90	2.07	2.07	37	31	.98	.80
1B4	.87	32.90	.82	1.96	1.96	36	29	.88	.73
1C4	.73	31.60	.76	2.01	2.01	34	29	.82	.68
1D4	.00	.00	.00	.00	.00	0	0	.00	.00
1A5	.00	34.70	1.32	.00	.00	37	31	1.41	1.18
1B5	.00	32.70	1.63	.00	.00	36	29	1.76	1.45
1C5	.00	31.50	1.76	.00	.00	34	28	1.90	1.57
1D5	.00	.00	.00	.00	.00	0	0	.00	.00
CDL	.04	4.00	.75	.17	.02	10	1	1.50	.25
SDL	1.06	47.80	2.20	1.40	.97	52	43	2.77	1.78

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
1A	6.33	1.67	.00	6.74	5.63	2.37	1.26	.00	.00
1B	6.41	1.59	.00	7.05	5.71	2.29	.95	.00	.00
1C	5.92	2.08	.00	6.31	5.37	2.63	1.69	.00	.00
C	3.22	4.78	.00	3.96	2.72	5.28	4.04	.00	.00
S1	7.38	.62	.00	7.63	7.23	.77	.37	.00	.00

truck 32.9 loads, and the Type C truck 31.6 loads. This represents a tonnage of 6085.3 tons. Management must now decide if the addition of the D truck is worth the additional 179.0 tons of ore per day over what a Type A, B, and C truck working together can dump. Any arrangement of truck number and type can just as easily be tested.

In the second example where MHSS was tested, the problem concerned the effective utilization of fork lift trucks and material handling personnel in a plant engaged in the manufacture of equipment for the atomic energy industry. Two fork lift trucks were assigned to 17 different cost centers in the plant. There was also two material handlers who operated the trucks and performed other material handling duties for these cost centers. These other duties involved the operation of floor controlled overhead cranes, moving material with a hand truck, or sometimes just hand carrying material from one location to another. The cost centers complained of excessive delays in waiting for moves to be executed by the fork lift trucks and management was attempting to alleviate this situation. There were several possible ways of accomplishing this. One would be to get one or more additional trucks. A second would be to hire one or more additional material handlers and a third would be an attempt to reduce truck down time. Production and work sampling studies were taken on the operation with the results shown in Figure 40.

Truck Utilization	22%
Material Handlers Busy	43%
Truck Down	50%
Av. Truck Down Time	3.0 Hours

Figure 40

The 17 cost centers and the average number of fork lift truck moves demanded per day are shown in Figure 41. Management felt the demands occurred in a random manner, and an examination of the data supported this fact. Therefore, the time between demands for a department would follow an exponential distribution with the mean = 8.0/number of demands. The length of time for each truck move was tallied from the production studies and a skewed to the right distribution resulted with a minimum value of two minutes and a maximum value of 26 minutes. A user furnished distribution was used for these times. The non-truck demands of the material handlers also occurred in a random manner. The average number of demands per shift for these types of moves was 39 which meant the average time between demands was .205 hours. A user furnished distribution was also developed for the length of time for these non-truck moves. In this case, the minimum value was one minute and the maximum value was 50 minutes.

The results of this simulation are shown on pages 104 to 116. From the summary report on page 116, it can be seen that the trucks were busy 18.3% ((1.86+1.03)/16). The operators were busy 40.0% ((4.18+2.22)/16), and the trucks were unavailable to the system 45.8% ((3.60+3.72)/16). These figures compare very favorably with the results from the work sampling study. The average wait time per truck move can be determined by adding AV. WAITS and dividing this sum by the sum of the AV. NO. MOVES column for all the truck moves. This gives

COST CENTER	DEMANDS PER SHIFT	
400	4.26	
402	1.25	
401	.25	
403	4.26	
404	.25	
405	5.26	
406	2.00	
407	2.03	
409	1.00	
410	1.50	
414	1.00	
471	.50	
472	.75	
XRY	.25	
SHP	4.00	
OUT	1.25	
800	2.25	
700	.75	
NTK	39.00	MOVE requires only one operator

COST CENTERS AND DEMANDS PER SHIFT

Figure 41

.355 hours as the average wait per truck for each move executed by the trucks. The maximum waits show that on some days waiting times in some of the departments exceeds five hours.

The summary report for ten simulated cycles with three trucks is shown on page 117. With this arrangement, the average wait per truck move is now .10 hours. The maximum wait for any department is less than two hours. Management can now decide if these savings are worth the cost of another fork lift truck.

The summary report for two trucks and three operators is shown on page 118. The wait time per truck move is .260 hours and the maximum waits are still in the four to five hour range for many departments. This arrangement can almost immediately be dropped from consideration since it shows little improvement over the two truck, two operator arrangement.

One final alternative that was examined was the reduction of truck down time. The summary report for ten cycles with truck down reduced to 20 per cent is shown on page 119. The average wait is now .038 hour and the maximums are almost all one hour or less. This would appear to be an attractive alternative to management since the results are better than could be obtained with the purchase of a third fork lift truck.

Confidence levels can be established on the results obtained from MHSS. For example, the two truck, two operator arrangement with 50 per cent truck down time gives total operator work times for the ten cycles as shown in Figure 42.

SYSTEM PARAMETERS

1. MOVE CODE
2. EQ. 1 REQUIRED
3. EQ. 2 REQUIRED
4. EQ. 3 REQUIRED
5. TIME START
6. TIME FINISHED
7. MOVE 1ST PARAMETER
8. MOVE 2ND PARAMETER
9. MOVE DISTRIBUTION
10. TIME BETWEEN MOVES 1ST PARAMETER
11. TIME BETWEEN MOVES 2ND PARAMETER
12. TIME BETWEEN MOVES DISTRIBUTION
13. OPTIONAL MOVE
14. TIME BEFORE OPTION
15. 1ST FOLLOWING MOVE
16. TIME TO 1ST FOLLOWING MOVE 1ST PARAMETER
17. TIME TO 1ST FOLLOWING MOVE 2ND PARAMETER
18. TIME TO 1ST FOLLOWING MOVE DISTRIBUTION
19. 2ND FOLLOWING MOVE
20. TIME TO 2ND FOLLOWING MOVE 1ST PARAMETER
21. TIME TO 2ND FOLLOWING MOVE 2ND PARAMETER
22. TIME TO 2ND FOLLOWING MOVE DISTRIBUTION
23. MOVE PRIORITY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
400	FT	UP		.00	8.00	-.00	-.00	21	1.86	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
402	FT	UP		.00	8.00	-.00	-.00	21	6.40	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
401	FT	OP		.00	8.00	-.00	-.00	21	32.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
403	FT	UP		.00	8.00	-.00	-.00	21	1.88	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
404	FT	UP		.00	8.00	-.00	-.00	21	32.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
405	FT	UP		.00	8.00	-.00	-.00	21	1.52	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
406	FT	OP		.00	8.00	-.00	-.00	21	4.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
407	FT	OP		.00	8.00	-.00	-.00	21	7.46	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
409	FT	UP		.00	8.00	-.00	-.00	21	8.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
410	FT	UP		.00	8.00	-.00	-.00	21	5.33	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
414	FT	UP		.00	8.00	-.00	-.00	21	8.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
471	FT	UP		.00	8.00	-.00	-.00	21	16.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
472	FT	OP		.00	8.00	-.00	-.00	21	10.70	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
XRY	FT	UP		.00	8.00	-.00	-.00	21	32.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
SHP	FT	UP		.00	8.00	-.00	-.00	21	2.00	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
OUT	FT	OP		.00	8.00	-.00	-.00	21	6.40	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
800	FT	UP		.00	8.00	-.00	-.00	21	3.56	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
700	FT	OP		.00	8.00	-.00	-.00	21	10.70	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0
NTK	OP			.00	8.00	-.00	-.00	22	.20	-.00	2		-.00		-.00	-.00	-0		-.00	-.00	-0	-0

EQ. CODE	TM. START	TM. FIN	PER. AV	TIME GONE	PARAMETERS	
FT	.000	8.000	.500	3.000	-.000	12
FT	.000	8.000	.500	3.000	-.000	12
UP	.000	8.000	1.000	-.000	-.000	-0
UP	.000	8.000	1.000	-.000	-.000	-0

REPORT AT 8.00 CYCLE NUMBER 1 AVERAGES TO DATE

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
400	.02	2	.25	.02	2.00	.25
402	.08	4	.44	.08	4.00	.44
401	.00	0	.00	.00	.00	.00
403	.98	4	.31	.98	4.00	.31
404	.00	0	.00	.00	.00	.00
405	.00	2	.27	.00	2.00	.27
406	.03	1	.08	.03	1.00	.08
407	1.04	2	.23	1.04	2.00	.23
409	.00	1	.05	.00	1.00	.05
410	1.50	1	.04	1.50	1.00	.04
414	.09	1	.06	.09	1.00	.06
471	.00	0	.00	.00	.00	.00
472	.00	0	.00	.00	.00	.00
XRY	.00	0	.00	.00	.00	.00
SHP	.13	5	.46	.13	5.00	.46
OUT	.06	1	.08	.06	1.00	.08
800	.01	3	.32	.01	3.00	.32
700	.00	1	.05	.00	1.00	.05
NTK	.12	30	3.35	.12	30.00	3.35

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	1.65	3.19	3.16	1.65	3.19	3.16
FT	.98	4.46	2.57	.98	4.46	2.57
OP	4.10	3.90	.00	4.10	3.90	.00
OP	1.87	6.13	.00	1.87	6.13	.00

REPORT AT MOVE CODE	8.00 WAIT TIME	CYCLE NUMBER 2 NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.00	2	.09	.01	2.00	.17
402	.00	0	.00	.04	2.00	.22
401	.00	0	.00	.00	.00	.00
403	.00	3	.41	.49	3.50	.36
404	.00	0	.00	.00	.00	.00
405	.00	3	.35	.00	2.50	.31
406	.11	1	.07	.07	1.00	.07
407	.00	3	.34	.52	2.50	.28
409	.15	1	.09	.08	1.00	.07
410	.08	1	.13	.79	1.00	.09
414	.00	1	.12	.04	1.00	.09
471	.00	1	.09	.00	.50	.04
472	.00	1	.13	.00	.50	.06
XRY	.00	0	.00	.00	.00	.00
SHP	.32	6	.73	.22	5.50	.59
OUT	.00	2	.31	.03	1.50	.19
800	.00	2	.18	.01	2.50	.25
700	.00	0	.00	.00	.50	.02
NFK	.78	34	4.35	.45	32.00	3.85

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	2.99	5.01	.00	2.32	4.10	1.58
FT	.04	1.90	6.06	.51	3.18	4.31
OP	4.07	3.93	.00	4.09	3.91	.00
OP	3.31	4.69	.00	2.59	5.41	.00

REPORT AT	8.00	CYCLE NUMBER 3		AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
400	4.01	1	.09	1.34	1.67	.14
402	5.67	1	.15	1.92	1.67	.19
401	.00	0	.00	.00	.00	.00
403	1.91	1	.05	.96	2.67	.26
404	.00	0	.00	.00	.00	.00
405	4.35	2	.16	1.45	2.33	.26
406	2.40	1	.05	.85	1.00	.07
407	6.02	2	.19	2.36	2.33	.25
409	2.77	2	.22	.98	1.33	.12
410	.00	0	.00	.53	.67	.06
414	1.84	1	.11	.64	1.00	.09
471	4.00	2	.13	1.33	1.00	.07
472	5.16	1	.08	1.72	.67	.07
XRY	.29	1	.23	.10	.33	.08
SHP	4.58	1	.10	1.67	4.00	.43
OUT	2.02	1	.11	.69	1.33	.16
800	2.12	0	.00	.71	1.67	.17
700	3.66	1	.06	1.22	.67	.04
NTK	.70	38	3.70	.53	34.00	3.80

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
FT	.00	.00	8.00	1.55	2.73	3.72
FT	1.72	.00	6.28	.91	2.12	4.97
UP	4.16	3.84	.00	4.11	3.89	.00
UP	1.26	6.74	.00	2.15	5.85	.00

REPORT AT 8.00 CYCLE NUMBER 4

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.05	3	.26	1.02	2.00	.17
402	.00	1	.06	1.44	1.50	.16
401	.00	0	.00	.00	.00	.00
403	.00	3	.21	.72	2.75	.25
404	.00	0	.00	.00	.00	.00
405	.00	3	.16	1.09	2.50	.23
406	.09	2	.49	.66	1.25	.17
407	.00	0	.00	1.77	1.75	.19
409	.00	1	.13	.73	1.25	.12
410	.10	3	.27	.42	1.25	.11
414	.00	2	.18	.48	1.25	.12
471	.00	1	.04	1.00	1.00	.07
472	.00	0	.00	1.29	.50	.05
XRY	.00	0	.00	.07	.25	.06
SHP	.03	6	.55	1.26	4.50	.46
OUT	.00	0	.00	.52	1.00	.12
800	.00	0	.00	.53	1.25	.12
700	.00	0	.00	.91	.50	.03
NTK	.14	29	2.86	.43	32.75	3.56

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	1.10	3.25	3.65	1.44	2.86	3.70
FT	1.25	4.58	2.17	1.00	2.74	4.27
OP	3.63	4.37	.00	3.99	4.01	.00
OP	1.58	6.42	.00	2.00	6.00	.00

REPORT AT 8.00 CYCLE NUMBER 5

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.00	2	.20	.82	2.00	.18
402	.03	2	.11	1.16	1.60	.15
401	.07	1	.07	.01	.20	.01
403	.11	4	.41	.60	3.00	.28
404	.00	0	.00	.00	.00	.00
405	.41	6	.94	.95	3.20	.37
406	.00	3	.41	.53	1.60	.22
407	.08	2	.22	1.43	1.80	.20
409	.00	2	.53	.59	1.40	.20
410	.00	1	.16	.34	1.20	.12
414	.00	2	.25	.38	1.40	.14
471	.00	0	.00	.80	.80	.05
472	.12	1	.07	1.05	.60	.06
XRY	.09	1	.05	.08	.40	.06
SHP	.13	1	.06	1.04	3.80	.38
OUT	.00	1	.06	.42	1.00	.11
800	.20	6	.69	.47	2.20	.24
700	.03	2	.10	.74	.80	.04
NTK	.73	41	3.26	.49	34.40	3.50

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	2.12	2.98	2.89	1.57	2.89	3.54
FT	2.21	5.79	.00	1.24	3.35	3.41
OP	4.64	3.36	.00	4.12	3.88	.00
UP	2.95	5.05	.00	2.19	5.81	.00

REPORT AT 8.00 CYCLE NUMBER 6

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.34	4	.27	.74	2.33	.19
402	.02	1	.07	.97	1.50	.14
401	.11	1	.03	.03	.33	.02
403	.16	1	.11	.53	2.67	.25
404	.00	0	.00	.00	.00	.00
405	.11	4	.33	.81	3.33	.37
406	.10	1	.08	.45	1.50	.20
407	.05	4	.36	1.20	2.17	.22
409	.15	2	.20	.51	1.50	.20
410	.00	1	.17	.28	1.17	.13
414	.04	2	.13	.33	1.50	.14
471	.00	1	.11	.67	.83	.06
472	.00	0	.00	.88	.50	.05
XRY	.00	1	.12	.06	.50	.07
SHP	.21	5	.59	.90	4.00	.41
DUT	.10	1	.03	.36	1.00	.10
800	.00	2	.36	.39	2.17	.26
700	.00	0	.00	.62	.67	.03
NTK	.17	32	2.22	.44	34.00	3.29

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	.49	.41	7.10	1.39	2.47	4.13
FT	2.49	5.36	.15	1.45	3.68	2.87
OP	3.32	4.68	.00	3.99	4.01	.00
OP	1.88	6.12	.00	2.14	5.86	.00

REPORT AT 8.00 CYCLE NUMBER 7

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.70	3	.81	.73	2.43	.28
402	.32	2	.17	.88	1.57	.14
401	.56	2	.19	.11	.57	.04
403	.57	4	.31	.53	2.86	.26
404	.94	0	.00	.13	.00	.00
405	1.51	6	.55	.91	3.71	.39
406	1.27	4	.32	.57	1.86	.21
407	.34	2	.11	1.08	2.14	.21
409	.21	1	.11	.47	1.43	.19
410	.14	1	.06	.26	1.14	.12
414	.23	1	.05	.31	1.43	.13
471	.36	1	.10	.62	.86	.07
472	.00	0	.00	.75	.43	.04
XRY	.00	0	.00	.05	.43	.06
SHP	.95	7	.78	.91	4.43	.47
OUT	.00	0	.00	.31	.86	.08
800	.18	3	.24	.36	2.29	.26
700	.06	1	.17	.54	.71	.05
NTK	.31	26	3.29	.42	32.86	3.29

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	3.98	2.68	1.34	1.76	2.50	3.73
FT	.00	.27	7.73	1.24	3.19	3.56
OP	4.68	3.32	.00	4.09	3.91	.00
OP	2.59	5.41	.00	2.20	5.80	.00

REPORT AT 8.00 CYCLE NUMBER 8

MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	.00	2	.12	.64	2.38	.26
402	.06	1	.10	.77	1.50	.14
401	.00	1	.05	.09	.63	.04
403	.00	5	.53	.47	3.13	.29
404	.00	0	.00	.12	.00	.00
405	.01	6	.51	.80	4.00	.41
406	.00	1	.13	.50	1.75	.20
407	.39	4	.38	.99	2.38	.23
409	.00	3	.39	.41	1.63	.21
410	.00	0	.00	.23	1.00	.11
414	.00	1	.04	.27	1.38	.12
471	.00	1	.10	.54	.88	.07
472	.00	0	.00	.66	.38	.03
XRY	.00	0	.00	.05	.38	.05
SHP	.00	4	.30	.79	4.38	.45
OUT	.07	1	.37	.28	.88	.12
800	.00	1	.14	.32	2.13	.24
700	.00	1	.03	.47	.75	.05
NTK	.26	29	3.77	.40	32.38	3.35

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	1.67	3.06	3.27	1.75	2.57	3.68
FT	1.53	6.47	.00	1.28	3.60	3.12
OP	4.30	3.70	.00	4.11	3.89	.00
UP	2.67	5.33	.00	2.26	5.74	.00

REPORT AT	8.00	CYCLE NUMBER 9		AVERAGES TO DATE		
MOVE CODE	WAIT TIME	NO. MOVES	HANDLING TIME	WAIT TM.	NO. MOVES	HANDLING TM.
400	2.27	2	.17	.82	2.33	.25
402	.00	0	.00	.69	1.33	.12
401	.00	0	.00	.08	.56	.04
403	.03	2	.16	.42	3.00	.28
404	.00	0	.00	.10	.00	.00
405	2.34	7	.65	.97	4.33	.44
406	2.47	2	.28	.72	1.78	.21
407	.27	3	.20	.91	2.44	.22
409	.43	2	.25	.41	1.67	.22
410	2.06	2	.17	.43	1.11	.11
414	1.29	1	.03	.39	1.33	.11
471	.00	1	.08	.48	.89	.07
472	.06	1	.05	.59	.44	.04
XRY	.00	0	.00	.04	.33	.04
SHP	.33	3	.34	.74	4.22	.44
OUT	2.02	2	.22	.48	1.00	.13
800	1.21	1	.10	.41	2.00	.23
700	.00	0	.00	.42	.67	.05
NTK	.39	31	2.59	.40	32.22	3.26

				AVERAGES TO DATE		
EQ. CODE	WORK	IDLE	AWAY	WORK	IDLE	AWAY
FT	2.72	2.77	2.51	1.86	2.60	3.55
FT	.00	.43	7.57	1.14	3.25	3.61
OP	3.97	4.03	.00	4.10	3.90	.00
OP	1.33	6.67	.00	2.16	5.84	.00

REPORT AT MOVE CODE	8.00 WAIT TIME	CYCLE NUMBER 10 NO. MOVES	HANDLING TIME	AVERAGES TO DATE WAIT TM.	NO. MOVES	HANDLING TM.
400	3.55	3	.39	1.09	2.40	.26
402	.00	1	.17	.62	1.30	.13
401	.00	0	.00	.07	.50	.04
403	2.15	3	.48	.59	3.00	.30
404	.00	0	.00	.09	.00	.00
405	3.61	4	.39	1.23	4.30	.43
406	.00	1	.13	.65	1.70	.20
407	3.35	3	.18	1.16	2.50	.22
409	.00	0	.00	.37	1.50	.20
410	1.04	1	.13	.49	1.10	.11
414	.00	0	.00	.35	1.20	.10
471	1.75	0	.00	.61	.80	.07
472	.00	0	.00	.53	.40	.03
XRY	.00	0	.00	.04	.30	.04
SHP	3.89	1	.16	1.06	3.90	.41
OUT	.04	1	.06	.43	1.00	.12
800	.00	2	.33	.37	2.00	.24
700	.00	0	.00	.37	.60	.04
NTK	.48	52	5.23	.41	34.20	3.46

EQ. CODE	WORK	IDLE	AWAY	AVERAGES TO DATE WORK	IDLE	AWAY
FT	1.87	2.02	4.11	1.86	2.54	3.60
FT	.56	2.82	4.63	1.08	3.21	3.72
OP	4.86	3.14	.00	4.18	3.82	.00
OP	2.79	5.21	.00	2.22	5.78	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HAND. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
400	1.09	2.40	.26	4.01	.02	4	1	.81	.09
402	.62	1.30	.13	5.67	.08	4	0	.44	.00
401	.07	.50	.04	.56	.00	2	0	.19	.00
403	.59	3.00	.30	2.15	.98	5	1	.53	.05
404	.09	.00	.00	.94	.00	0	0	.00	.00
405	1.23	4.30	.43	4.35	.00	7	2	.94	.16
406	.65	1.70	.20	2.47	.03	4	1	.49	.05
407	1.16	2.50	.22	6.02	1.04	4	0	.38	.00
409	.37	1.50	.20	2.77	.00	3	0	.53	.00
410	.49	1.10	.11	2.06	1.50	3	0	.27	.00
414	.35	1.20	.10	1.84	.09	2	0	.25	.00
471	.61	.80	.07	4.00	.00	2	0	.13	.00
472	.53	.40	.03	5.16	.00	1	0	.13	.00
XRY	.04	.30	.04	.29	.00	1	0	.23	.00
SHP	1.06	3.90	.41	4.58	.13	7	1	.78	.06
OUT	.43	1.00	.12	2.02	.06	2	0	.37	.00
800	.37	2.00	.24	2.12	.01	6	0	.69	.00
700	.37	.60	.04	3.66	.00	2	0	.17	.00
NTK	.41	34.20	3.46	.78	.12	52	26	5.23	2.22

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
FT	1.86	2.54	3.60	3.98	.00	5.01	.00	8.00	.00
FT	1.08	3.21	3.72	2.49	.00	6.47	.00	7.73	.00
UP	4.18	3.82	.00	4.86	3.32	4.68	3.14	.00	.00
UP	2.22	5.78	.00	3.31	1.26	6.74	4.69	.00	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HAND. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
400	.46	5.40	.55	1.25	.00	9	3	1.28	.15
402	.18	.90	.09	.86	.00	2	0	.35	.00
401	.22	.30	.04	1.74	.00	1	0	.23	.00
403	.23	3.50	.35	1.66	.03	8	1	.77	.07
404	.13	.20	.02	1.27	.00	1	0	.16	.00
405	.33	4.70	.50	1.28	.06	9	2	.86	.15
406	.21	1.50	.19	1.15	.04	3	0	.51	.00
407	.28	2.60	.33	1.30	.00	5	1	.62	.04
409	.16	1.10	.13	1.13	.04	3	0	.44	.00
410	.20	1.60	.18	1.22	.00	3	0	.39	.00
414	.06	.60	.09	.58	.00	3	0	.30	.00
471	.10	.80	.07	.64	.00	2	0	.14	.00
472	.01	.40	.05	.06	.00	2	0	.31	.00
XRY	.02	.30	.02	.19	.00	1	0	.12	.00
SHP	.24	2.90	.32	.91	.00	6	0	.59	.00
OUT	.00	.80	.09	.00	.00	2	0	.22	.00
800	.18	2.60	.30	.91	.00	4	0	.64	.00
700	.06	.80	.11	.48	.00	3	0	.47	.00
NTK	.47	35.70	3.40	.89	.27	49	23	5.49	1.91

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
FT	1.89	3.62	2.49	3.70	.06	5.53	.65	7.09	.00
FT	.58	3.56	3.86	1.53	.00	6.91	.00	8.00	.00
FT	.96	4.06	2.98	3.00	.00	8.00	.17	6.40	.00
OP	4.27	3.73	.00	5.44	3.07	4.93	2.56	.00	.00
OP	2.55	5.45	.00	4.16	1.46	6.54	3.84	.00	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HAND. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
400	.71	3.20	.38	1.99	.09	6	1	.95	.12
402	.16	1.50	.16	1.20	.00	3	0	.56	.00
401	.27	.20	.02	1.99	.00	1	0	.15	.00
403	.99	3.60	.34	4.42	.20	6	2	.65	.18
404	.01	.30	.03	.08	.00	1	0	.12	.00
405	.56	5.30	.51	1.95	.26	11	3	1.00	.32
406	.46	2.10	.20	2.28	.00	3	1	.31	.04
407	1.07	2.90	.31	5.49	.00	4	1	.58	.07
409	.19	.90	.12	1.16	.08	2	0	.45	.00
410	.68	.80	.08	4.78	.01	2	0	.24	.00
414	.64	1.00	.11	3.43	.00	2	0	.28	.00
471	.20	.50	.04	1.10	.00	2	0	.19	.00
472	.33	.90	.10	2.01	.00	2	0	.25	.00
XRY	.02	.40	.07	.15	.00	1	0	.28	.00
SHP	.64	4.30	.53	3.24	.52	8	1	1.04	.12
OUT	.24	1.10	.09	1.46	.12	3	0	.25	.00
800	.58	2.10	.21	2.05	.00	5	1	.43	.05
700	.48	.60	.07	4.57	.00	1	0	.29	.00
NTK	.04	40.90	4.20	.18	.06	50	29	5.80	3.00

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
FT	2.24	3.16	2.60	3.55	.34	6.05	.62	7.05	.00
FT	1.13	2.93	3.93	3.66	.00	6.76	.14	7.14	.00
OP	4.59	3.41	.00	5.36	3.70	4.30	2.64	.00	.00
UP	2.28	5.72	.00	3.12	1.17	6.83	4.88	.00	.00
OP	.70	7.30	.00	1.57	.22	7.78	6.43	.00	.00

SUMMARY REPORT

MOVE CODE	AV. WAIT	AV. NO. MOVES	AV. HAND. TM.	WAIT TIMES MAX	WAIT TIMES MIN	MOVES MAX	MOVES MIN	HANDLING TIMES MAX	HANDLING TIMES MIN
400	.17	3.10	.27	.98	.01	5	1	.47	.04
402	.11	1.00	.08	.97	.00	2	0	.15	.00
401	.00	.00	.00	.00	.00	0	0	.00	.00
403	.11	4.10	.40	.64	.00	6	1	.75	.10
404	.00	.40	.03	.00	.00	1	0	.12	.00
405	.18	5.20	.51	.93	.02	11	1	.85	.05
406	.05	2.10	.19	.30	.00	4	1	.34	.03
407	.05	2.50	.25	.16	.01	5	1	.60	.05
409	.00	.80	.11	.04	.00	3	0	.41	.00
410	.13	1.40	.14	.81	.03	4	0	.42	.00
414	.13	.70	.07	1.22	.00	3	0	.32	.00
471	.01	.60	.06	.06	.00	2	0	.19	.00
472	.01	.80	.11	.09	.00	2	0	.32	.00
XRY	.00	.10	.01	.00	.00	1	0	.10	.00
SHP	.09	4.20	.41	.22	.08	6	2	.63	.18
OUT	.03	1.30	.17	.12	.00	3	0	.86	.00
800	.07	1.90	.17	.40	.00	5	0	.42	.00
700	.04	.80	.07	.23	.14	3	0	.20	.00
NTK	.39	35.90	3.74	.77	.45	42	31	4.91	2.46

EQ. CODE	AV. WORK	AV. IDLE	AV. AWAY	WORK MAX	WORK MIN	IDLE MAX	IDLE MIN	AWAY MAX	AWAY MIN
FT	2.33	4.64	1.03	2.77	1.55	5.68	2.21	4.23	.00
FT	.73	5.87	1.40	1.68	.31	7.66	2.02	5.66	.00
OP	4.31	3.69	.00	5.11	3.46	4.54	2.89	.00	.00
OP	2.48	5.52	.00	3.26	1.44	6.56	4.74	.00	.00

CYCLE	WORK TIME
1	5.97
2	7.38
3	5.42
4	5.21
5	7.59
6	5.20
7	7.27
8	6.97
9	5.30
10	7.65

OPERATOR WORK TIMES

Figure 42

The mean work time is 6.396 hours, and the standard deviation is 1.066 hours. For a 95 per cent confidence interval, the t value for nine degrees of freedom is 2.262. Therefore, the confidence interval would be:

$$(14) \quad 6.396 \pm 2.262 \frac{1.066}{\sqrt{10}} = 5.634 \text{ hrs. to } 7.158 \text{ hrs.}$$

Ten cycles were used in both the examples, mainly for convenience. It was desired to have one complete run for each example included in the dissertation, and if more than ten runs per example were used, it was felt the number of pages would have been excessive. Computer time and cost would not have been much more if a hundred or more cycles had been run. The confidence intervals, of course, are much narrower the more cycles the simulations is run,

V. CONCLUSION

It is hoped that the successful use of MHSS in the examples presented in the previous section, will stimulate others to using the system with their own applications. It is not claimed that MHSS will always have the accuracy and success demonstrated in the two examples. Material handling systems may exist where the MHSS model will not apply. However, in all the cases examined where simulation was utilized in the material handling area, there were no situations in which MHSS could not have been used to some extent.

The majority of material handling systems consist of a set of moves, and a set of pieces of equipment required to execute the moves. MHSS gives a technique for describing and classifying the elements in these sets, and then a technique for simulating the interactions of these elements as the material handling system operates.

Even if the simulation features were not available, MHSS would still make a contribution to the Industrial Engineering profession. In discussing material handling systems with management personnel, it was surprising to see how often little or no documentation of their material handling systems existed. A request to see a plan of the existing material handling system, resulted sometimes in a list of material handling equipment, sometimes in a flow chart of the path material took through a plant, and sometimes in nothing at all. MHSS gives a precise way of documenting a material handling system that will show the moves required in the system, the equipment available to execute these moves, and information on when and how long the moves take. This information seems to be lacking in many instances today, and should be available before anyone can talk intelligently about their material handling system.

In addition to providing a means for describing an existing material handling system, MHSS also provides the user with a method whereby he can test the results of possible changes in the system easily and quickly. A user can test what will happen if more, or less, or different material handling equipment is made available to his system. A user can test what will happen if demands for some or all the moves in his existing system are increased or decreased. He can test what will happen if entirely new moves are added to his system, and he can use MHSS to help him determine what material handling equipment will best handle the new moves. A problem comes up very often in industrial situations where management keeps adding more and more production facilities without providing additional material handling facilities. Each new production facility causes more demands on the material handling system, and moves must wait longer and longer as the demands increase. Using MHSS, the addition of a new production facility would require someone to decide on what material handling equipment will serve this facility. The effect of this change in the handling system can be tested, and might show that to service this new facility with the present equipment will cause a sharp decrease in the efficiency of service to the existing production facilities

MHSS provides for modular analysis and development of a material handling model. In the fork lift truck example, only the moves involving the fork lift trucks were considered in the model, because that was where the immediate concern was focused. A great deal of other material handling equipment and moves existed in this plant. Management at a later date could add the cranes and their related moves to the model, and then still later, the remainder of the equipment and its moves. Each addition could be treated separately or combined with already existing data for the model. Meaningful information can be obtained without modeling the entire system.

MHSS is simple to use. This has been one of the main considerations in preparing the computer program. One card for each move, and one card for each piece of equipment makes additions, deletions, or changes in the system an easy matter. An explanation of MHSS and a description of the data required to utilize it never took more than three hours where it was tested. In many cases, a great deal of the data required for its use is already available. In a machine shop under an incentive plan, for example, the time between moves for each machine can be found very quickly by referring to production records.

MHSS is inexpensive to use. The mining example with four trucks required fifty seconds of execution on an IBM 7090 for ten cycles. At $450.00 per hour, this comes to $6.25. When the end of cycle reports were suppressed, the execution time was reduced to 41 seconds. The fork lift truck example required 16 seconds for ten cycles when all the end of cycle reports were printed. For 50 cycles, the time was 21 seconds, and for 150 cycles, 65 seconds. In the latter two cases, the end of cycle reports were suppressed.

APPENDIX A

INPUT FORMAT FOR MHSS

Specification Card

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
1- 5	NOSSM	Number of Cycles	I5
6-10	HRSH	Time Per Cycle	F5.0
11-15	IHOW	Blank for end of cycle reports. Any positive number to suppress end of cycle reports.	I5
16-20	NSEED	Seed for Random Number Generator	I5

Equipment Card

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
1- 3	JEQ	Equipment Code	A3
4- 7	TMEQS	Start of Equipment Availability Period	F4.0
8-11	TMEQN	Finish of Equipment Availability Period	F4.0
12-15	PEQAV	Proportion of Time Equipment Available	F4.0
16-19	TEQGN	First Parameter for Time Equipment Gone	F4.0
20-23	TEQ2P	Second Parameter for Time Equipment Gone	F4.0
24-26	JEQGD	Distribution for Time Equipment Gone	I3

Move Card

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
1- 3	MC	Move Code	A3
4- 6	MOWN	If move is optional move, move that it is owned by, otherwise blank.	A3
7	MFPON	If move is following move 1, otherwise blank.	I1
8-10	JEQR1	First piece of Requird Equipment	A3
11-13	JEQR2	Second Piece of Required Equipment	A3
14-16	JEQR3	Third Piece of Required Equipment	A3
17-20	TMLST	Start Period for Move	F4.0
21-24	TMLFN	Finish Period for Move	F4.0
25-28	TMMIN	First Parameter for Move Time	F4.0
29-32	TMMAX	Second Parameter for Move Time	F4.0
33-34	MDIS	Distribution for Move Time	I2
35-38	TNMMN	First Parameter for Time Between Demands	F4.0
39-42	TNMMX	Second Parameter for Time Between Demands	F4.0
43-44	NMDIS	Distribution for Time Between Demands	I2

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
45-47	MCOP	Optional Move Code	A3
48-51	TMCOP	Time Rather than Option	F4.0
52-54	MCFOL	First Following Move	A3
55-58	T1FC1	First Parameter for Time to First Following Move	F4.0
60-62	F1FL2	Second Parameter for Time to First Following Move	F4.0
63-64	JD1FL	Distribution for Time to First Following Move	I2
65-67	MCFL2	Second Following Move	A3
68-71	T2FL1	First Parameter for Time to Second Following Move	F4.0
72-75	T2FL2	Second Parameter for Time to Second Following Move	F4.0
76-77	JD2FL	Distribution for Time to Second Following Move	I2
78	MPRI	Move Priority	I1
79	MBLK	1 if blocked moves are to follow; otherwise blank	I1

Blocked moves appear on cards immediately following blocking move which affects them. One blocked move per card with move code in the first three columns under A3 specification. Blank card signifies end of blocked move list.

User Distribution Designation Card

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
1- 5	$NDIS_1$	Blank if no user furnished distributions are used. Otherwise, the user assigned number for the first distribution	I5

User Distribution Data Card

COLUMNS	VARIABLE	DESCRIPTION	SPECIFICATION
1-80	$X_{J,I}$ $P_{J,I}$	Points for the user furnished distribution	16F5.0

BIBLIOGRAPHY

1. Markowitz, H.M. Hausner, B., and Karr, H.W., SIMSCRIPT: A Simulation Programming Language. Santa Monica, California: The RAND Corporation, November, 1962.

2. Kiviat, Philip J., and Colker, Alan, GASP-A General Activity Simulation Program. Santa Monica, California: The RAND Corporation, February, 1964.

3. Buffa, E.S., Armour, G.C., and Vollman, T.E., "Allocating Facilities with CRAFT," Harvard Business Review, March-April, 1964.

4. Lave, R.E., and Taha, H.A., "A Program For Simulating the Operation of an Overhead Crane," Journal of Industrial Engineering, March, 1965.

5. Hunley, O.R., "Simulation Finds the One Best Conveyor Layout," Modern Materials Handling, October, 1963.

6. Blake, K. and Gordon, G., "Systems Simulation with Digital Computers," IBM Systems Journal, Vol. 3, No. 1, 1964.

7. Chu, K. and Naylor, T.H., "Two Alternative Methods for Simulating Waiting Line Models," Journal of Industrial Engineering, November-December, 1965.

8. Churchman, C.W., Ackoff, R.L., and Arnoff, E.L., Introduction to Operations Research. New York: John Wiley and Sons, Inc., 1957.

9. Fetter, Robert B., Galliher, Herbert P., "Waiting Line Models in Materials Handling," Journal of Industrial Engineering, May-June, 1958.

10. Gould, Arthur F., "Analytical Methods for Materials Handling Analysis," American Society of Mechanical Engineers Journal, June, 1957.

11. O'Neill, J., "Analysis and Monte Carlo Simulation Cargo Handling," Naval Research Logistics Quarterly, September, 1957.

12. Heitner, I., "How Operations Research Aids Materials Handling," Modern Materials Handling, August, 1957.

13. Naylor, T.H., Balintfy, J.L., Burdick, D.S., and Chu, K., Computer Simulation Techniques. New York: John Wiley and Sons, Inc., 1966.

14. Teichroew, D., and Lubin, J.F., "Computer Simulation -- Discussion of the Technique Comparison of Languages," Communications of the ACM, October, 1966.